MIT Technology Review

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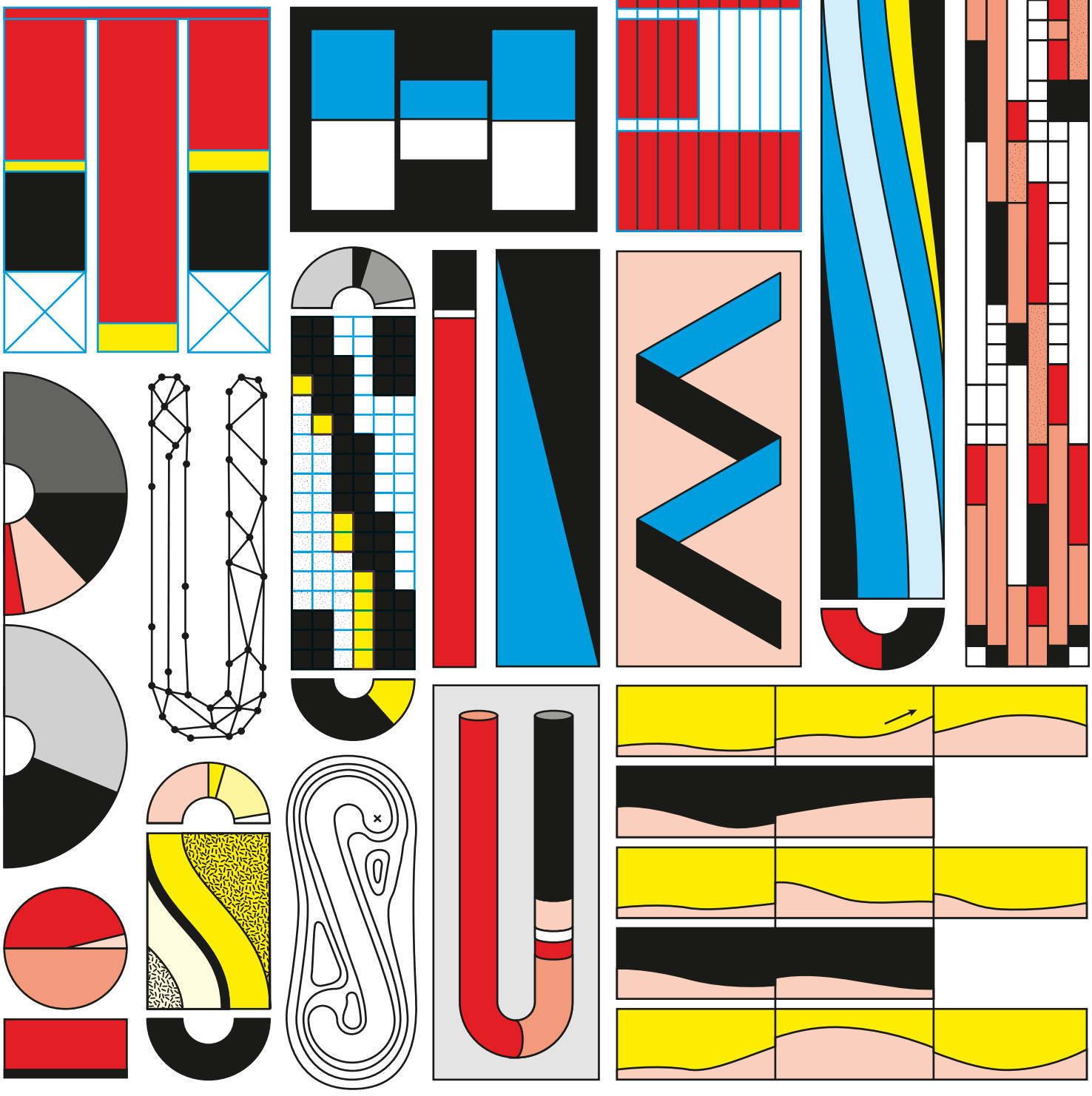
Including

50 Smartest Companies 2015



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From the Editor

GUIDO VITTI

In conceiving the stories in this Business Issue of *MIT Technology Review*, we meant to do business journalism our own way. We chose stories about how new technologies are affecting companies and markets—stories that reflect our way of seeing the world.

That mode of perception is mostly concerned with how novel technologies allow people to do things they couldn't before, but it is cognizant of the formidable challenges related to commercializing products and services that billions will use. We didn't want to publish traditional narratives of public companies and startups (that debased and debasing genre), nor laudatory profiles of chief executives and founders (because such pieces shed little light upon the ventures and what they make).

Instead, you'll read about the race by pharmaceutical companies to deliver immunotherapy for cancer (see "Biotech's Coming Cancer Cure," by Antonio Regalado, page 36) and about how Google and Apple are striving to own the operating system of our future cars (see "Rebooting the Automobile," by Will Knight, page 54). You'll find interviews with people of whom you've possibly never heard, like the head of OvaScience, a biotechnology company that adds mitochondria to women's eggs to increase fertility (see "Slowing the Biological Clock," page 60). The most conventional thing in this package of stories is our annual list of the 50 smartest companies in the world (page 45); but even here we hope the selection of businesses provokes.

One of the most dispiriting characteristics of much of business journalism is its relentless Panglossian cheerfulness: it can read like a form of propaganda. But all technological disruptions produce both winners and losers, and the impact of automation and digital technologies upon the most important market of all—labor—has been especially challenging.

In the Business Issue's anchoring essay, David Rotman, *MIT Technology Review*'s editor, writes:

"It is notoriously hard to determine the factors that go into job creation and earnings, and it is particularly difficult to isolate the specific impact of technology from that of, say, globalization, economic growth, access to education, and tax policies. But advances in technology offer one plausible, albeit partial, explanation for the decline of the middle class."

Lord Keynes described the "maladjustment" due to "our discovery of means of economising the use of labour" as "technological unemployment." Rotman's essay analyzes different prescriptions for technological unemployment and explains why they wouldn't help (as would be the case with a guaranteed minimum income) or are promising but insufficient to the scale of the problem (like education to prepare workers for technology-intensive jobs).

Elsewhere in this package of stories, a congregation of technology luminaries and business school professors offer their own responses to inequality. They say the "evidence is clear" that the benefits of a digital and interlinked world "have been very uneven" (see "Open Letter on the Digital Economy," page 11), and they "call on business leaders to develop new organizational models and approaches that not only enhance productivity and generate wealth but also create broad-based opportunity," adding, "The goal should be inclusive prosperity."

Or as Rotman glosses this approach in his essay: if the returns to capital have outpaced the benefits to labor in our technological civilization, then perhaps more people need to own the robots.

But write to tell me what you think at jason.pontin@technologyreview.com.

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Sangeeta Bhatia

2014 $500,000 Lemelson-MIT Prize winner

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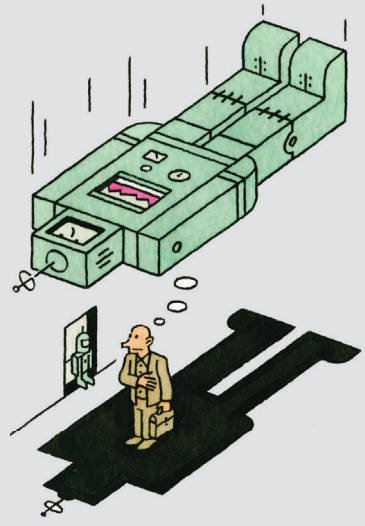
The Business Issue



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Morgan Stanley

Capital Creates The Next Episode

Great entertainment enriches our culture. When Netflix wanted to produce original programming and expand internationally, Morgan Stanley helped secure the funds. The financing helped Netflix become the world's leading Internet television network. Netflix has grown to 60 million members in more than 50 countries and changed the way we watch TV. From the writers' room to your living room, we're helping fund the culture that makes us think, question and feel more. Capital creates change.

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Netflix has grown to 60 million members in more than 50 countries, as disclosed in its SEC filing on Form 10-Q for the quarterly period ended March 31, 2015.

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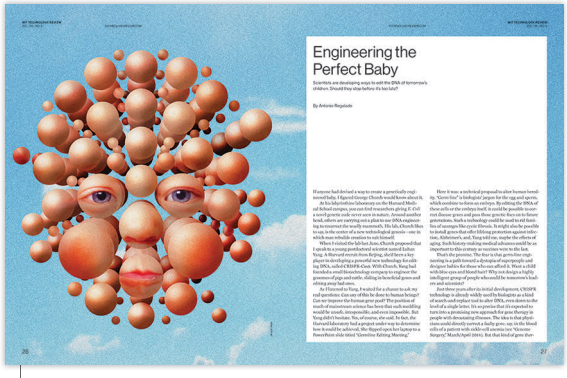
Five Most Popular Stories

MIT Technology Review
Volume 118, Number 3



1

Engineering the Perfect Baby

People equate every genetic breakthrough with either "designer babies" or Frankenstein. If a single DNA letter is known to cause a disabling disease, then parents should have the option to cure their children. This is not superficial blue eyes vs. green eyes bullshit. **—PitchforksVsPetriDishes**

We've been doing this for millennia the good old-fashioned way. I know a former professional baseball player who would only marry a woman who belonged to Mensa. The difference here is that the successful spouse-to-be is already alive. **—taw**

2

The Problem with Fake Meat

Raising animals for food is one of our worst environmental problems. Food writers need to be dragged kicking and screaming into the real world. Either help make something better or get out of the way. **—Pact**

If you are going to be vegetarian, then be a vegetarian. Don't re-create the experience of meat with non-meat products. There are lots of cuisines that vegetarians can draw from instead of trying to create a mock meat facsimile of the Western diet from a pastiche of highly processed vegetable proteins. **—rapier1**

3

Paralyzed Again

In health care, pharma or the manufacturer sets the price, and then the onus is on the insurers, who take the blame when they won't pay for it. Working in oncology, I see new lines of medications that are priced to the heavens. Maybe if the cost of the equipment weren't so high, it could have been used more and helped more people. Since the tech is already in place, maybe it can be brought back to life at a cheaper price and still be profitable. Dare to dream. **—mfolbe**

4

Machine Dreams

You have to admire what HP is attempting to do here, even if its shareholders may not be that keen. Being the game-changer has its risks. **—brettster**

HP is about to squander an opportunity. There are two main problems in computer science today: the low energy efficiency of existing RAM and processors, and then the harder problem—the low performance caused by the Von Neumann bottleneck. HP can make a killing by just solving the first problem. Low-energy, high-capacity, memristor-based memory will take over the market. They should stop right there. **—Mapou**

5

Survival in the Age of Spotify

The term "digital rights management" was chosen by the perpetrators of those restrictions to put a positive spin on them. If you don't agree with their spin, why repeat it? We should call it "digital restrictions management." **—Richard Stallman**

I'm geeking out that two of my favorite artists are having this conversation, but couldn't you argue that there's already plenty of good music? If the new structures deter half of all would-be artists, wouldn't that still leave plenty of musicians who can change a teenager's life? **—akwhitacre**

Too Early to Be Cured

My daughter Carys was born with a severely debilitating neurological condition called Rett syndrome, in her case caused by a single mutation on the *MECP2* gene. Mouse studies show it may be reversible even into adulthood, if only we could correct this mutation consistently throughout the body, and especially in the brain.

The CRISPR technology you write about in "Engineering the Perfect Baby" (May/June 2015) is 10 years away from a viable treatment, and this is probably too late for Carys. My mother reminds me of how polio was such a scourge in the 1940s. It seems our fate is to be parents who had a child a few years too early to be cured.

I envision a day when a baby's DNA is sequenced at birth. As you prepare to leave the hospital, your child receives an injection, a viral payload fixes a few genetic abnormalities such as Rett syndrome or cystic fibrosis, and you think nothing more of it.

I pray for this day so that others don't have to deal with the huge distress a diagnosis such as ours causes. I ask simply that rightful concerns about "vanity" editing of the genome don't derail this effort, even for a single day.

—James Westgate

The CRISPR technology you write about is 10 years away from a viable treatment. It seems our fate is to be parents who had a child a few years too early to be cured.

It's Not "Corporatese"!

As the chief architect of HP Labs working to realize the Machine as a practical, working system, I enjoyed Tom Simonite's article ("Machine Dreams," May/June 2015), but I had to chuckle when he wrote that "Unbound Convergence," a paper that I coauthored, had a "corporatese" title. It appears that you may have let your classics studies lapse. The "Unbound" part came from me—it's my reference to *Prometheus Unbound*, Shelley's lyric drama recasting the Promethean myth as the struggle of free will against the tyranny of conventional behavior. Sound familiar? Breaking the tyranny of conventional thought and yielding a new age of freedom based on reason? That's why I come in to work.

—Kirk Bresniker

The Plight of Early Adopters

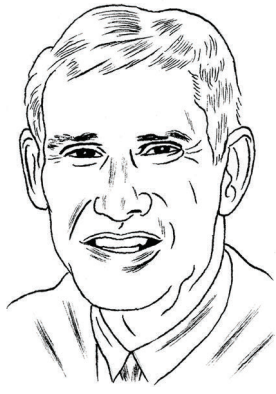
My sister experienced something similar to what Brian Bergstein describes in "Paralyzed Again" (May/June 2015), though with my sister it was eye-related. Being extremely myopic, she participated in a study in Minnesota with a glass lens implant. For extreme myopia, laser surgery works at first, but as the tissue ages, some myopia returns, whereas the glass lens holds its corrective shape over time.

The first implant, in one eye, worked perfectly. A year later she went to get the second implant only to discover that the company supplying the lens had been purchased by a contact lens manufacturer and the implant had been taken off the market.

Now my sister has one good eye and one bad. It's almost impossible to get decent eyewear, as one lens totally outweighs the other. I am not in any way trying to compare partial blindness with paralysis, but it is about the ethics of medical-device evolution for the early adopters and the companies involved. —David Kuller

Views

Julie Guillot



Eric Topol

Erik Brynjolfsson

BIOMEDICINE

Fighting for Zach

The treatment for cancer is often as devastating as the disease itself.

When my oldest son, Zach, was five years old, he was diagnosed with an aggressive type of cancer called acute myeloid leukemia.

The diagnosis was a nightmare. What came next was worse.

Soon after the diagnosis, Zach began the first of many rounds of chemotherapy so strong it was near the limits of what a human can tolerate. He downed dozens of pills and tearfully endured countless pokes, scans, bone marrow aspirations, spinal taps, and more. Drugs were injected directly into his spinal fluid, then his body. He suffered uncontrollable 105° fevers, unrelenting nausea, and hours-long nosebleeds—just a few of the side effects of the treatment we were grateful to have. His skin burned (literally) from the inside out. Each dose of chemo, in its attempt to kill every cancerous blood cell, killed healthy cells as well, causing hair loss, plummeting blood counts, and near zero immunity, resulting in life-threatening infections.

He'd say to me, "Mom, I'm scared I'm not going to make it. I want to live!" He was willing to try anything, and did.

Zach received every therapy available, both mainstream and experimental, in three top hospitals. Despite all of this, I watched him die in the ICU at just nine years old—not from cancer but from treatment toxicity following a third bone marrow transplant, which left him bleeding uncontrollably from a chemo-damaged liver.

I am the only family member who has ever read Zach's autopsy report. It was beyond painful to read but eye-opening in its revelation of the way current treatment regimens left a damaging mark on every organ system. I knew there had to be a better way, and this thought consumes me daily.

I know many mothers who, following the death of a child, are virtually incapacitated, frozen in grief. I often wonder what's wrong with me, because having loved Zach with every fiber of my body and fought wildly to save him, I should be frozen with them. Instead, I am obsessively driven to "get the monster" that took my kid, and to save other families from this torture.

Thankfully, new and better treatments are on the horizon—cutting-edge approaches like antibody-based therapies and reëngineered T cells that harness the power of the immune system (see "Biotech's Coming Cancer Cure," page 36). Such approaches might have saved Zach, and they have the potential to cure people without the collateral damage that can ruin lives. I met a man recently who could not run because he was cured of his childhood leukemia but the treatment destroyed his hips. There's a five-year-old now in Seattle Children's Hospital whose best option is a bone marrow transplant, but a round of chemo has damaged her heart to the point that she can't endure the procedure.

Zach's treatment took us to Seattle's Fred Hutchinson Cancer Research Center, where we learned about a new treatment using T-cell receptor technology showing promise in clinical trials against AML and in preclinical trials against killers such as lung, pancreatic, and ovarian cancers.

Even more exciting is that this T-cell receptor treatment targets *only* cancer cells, leaving healthy cells alone. The vision of a day when the need for chemo, radiation, and bone marrow transplants is greatly reduced or even eliminated, and a safer, simpler cure works for life, is what drives me. I now spend all my time raising funds to speed the development of this next generation of reëngineered T

ANDY FRIEDMAN

cells in the lab of Dr. Phil Greenberg at Fred Hutchinson.

I do it because I've seen the true face of cancer. I do it because it feels better to stay in the fight than to walk away, defeated. Most of all, I do it for Zach and all the kids like him.

Julie Guillot, a former IT consultant and executive, dedicates her time to raising her two surviving children and helping to speed less toxic cancer therapies.

MOBILE

Watch This

Medical sensors will make wearable tech indispensable for all of us.

Wearable devices were supposed to make us smarter and healthier. They were supposed to provide useful data that was previously difficult or even impossible to attain. But activity trackers—the vanguard of the wearables era—have by and large been a failure (see "The Struggle for Accurate Measurements on Your Wrist," page 74). Yes, they've counted steps and been used by tens of millions of people, but they haven't been durable and they haven't measurably improved our fitness levels.

Yet there's optimism that by 2020 there will be a trillion digitally connected sensors worldwide. Why?

We're moving away from lifestyle apps and moving instead toward medical apps that can monitor almost any common chronic illness. A low-cost fingertip sensor can not only obtain your electrocardiogram but also provide an instant, accurate interpretation. The FDA has approved this simple consumer device, which has the potential to be useful for the 20 million Americans who have heart rhythm disorders or are being evaluated for a possible arrhythmia. We also have skin-adhesive patches that capture heart rhythm, oxygen concentration in the blood, and respiratory rate. We have watches that obtain continuous blood pressure readings and sensors that continuously measure glucose. Clusters of sensors are being developed to track asthma, depression, heart failure, movement disorders, sleep apnea, and many other conditions.

Many people are skeptical that the Apple Watch will be useful for medical purposes, but even in its recently released first version, I've found it be to remarkably useful for what I call "glucose glances," with haptic notifications for high or low sugar levels (via an app that also requires a small sensor to be embedded under the skin). A medication app for the watch is very handy for providing reminders and tracking adherence.

But wearables are destined to be transformative beyond matters of convenience. They provide real-world, real-time streaming of medical data. Until now, we've practiced one-off medicine. We've had no insight about an individual's blood pressure during stressful moments or sleep, for example. Wearables can give us that, as well as the potential to improve how we analyze data being generated from many sources and sensors. Eventually, we'll see a "Dr. Siri" virtual medical coach with data analysis capabilities that surpass those of most human beings.

Wearables still face some challenges. They'll need to be validated in clinical trials. They'll need to be inexpensive so people will buy them in the first place. We'll have to find ways to harvest data from large cohorts of patients with particular medical conditions without compromising privacy and security.

And we'll have to get better at interpreting the data. We can generate terabytes of streaming vital-sign data, but for now we're long on hoarding and short on analytics.

Some fear only the wealthy will benefit from wearable medicine. I actually think it might make sense to give poor people smartphones, sensors, and data plans—it would still be a lot cheaper than emergency room visits or hospitalizations.

This is a strategy that can work all over the world. Wherever there's a mobile signal, there's an opportunity for better health care.

Eric Topol is a professor of genomics at the Scripps Research Institute and the author of The Patient Will See You Now.

INNOVATION

Open Letter on the Digital Economy

A group of technologists, economists, and investors propose a way that technological development can happen more fairly.

We are in the early stages of an era of great technological change. Digital innovations are remaking our industries, economy, and society just as steam, electricity, and internal combustion did before them. Like their predecessors, computers and their kin are engines of great prosperity. Progress with hardware, software, and networks is improving our lives in countless ways and creating immense value. To take just a few examples, advances in artificial intelligence are helping doctors diagnose disease, new sensors are making it possible to drive cars more safely, digitization is delivering knowledge and entertainment more widely than ever, and mobile networks are interconnecting the planet's population for the first time ever. The digital revolution is the best economic news on the planet.

But the evidence is clear that this progress is accompanied by some thorny challenges. The majority of U.S. house-

Views

holds have seen little if any income growth for over 20 years, the percentage of national income that's paid out in wages has declined sharply in the U.S. since 2000, and the American middle class, which is one of our country's great creations, is being hollowed out. Outsourcing and offshoring have contributed to these phenomena, but we should keep in mind that the recent wave of globalization is itself reliant on advances in information and communication technologies. The fundamental facts are that we're living in an ever more digital and interlinked world, and the benefits of this technological surge have been very uneven.

Previous surges brought with them greatly increased demand for labor and sustained job and wage growth. This time around, the evidence is causing some people to wonder if things are different. Or, to paraphrase many recent headlines, will robots eat our jobs?

We think this is the wrong question, because it assumes that we are powerless to alter or shape the effects of technological change on labor.

We reject this idea.

Instead, we believe that there's a great deal we can do to improve prospects for everyone. We propose a three-pronged effort.

First, we recommend a set of basic public policy changes in the areas of education, infrastructure, entrepreneurship, trade, immigration, and research. There's a strong consensus that these can quickly improve America's economy and the well-being of its workforce. It's also time to start a conversation about the deeper changes that will be necessary over the longer term—to our tax and transfer system, to the nature and extent of our public investment, and even to how democracy can and should function in a networked world.

Second, we call on business leaders to develop new organizational models and approaches that not only enhance productivity and generate wealth but also create broad-based opportunity. The goal should be inclusive prosperity. The corporation is itself a powerful innovation, and one that can do far more than just generate profits and provide a competitive return to those who supply capital and take risk. It is both a tool for transforming ideas into products and services that address society's challenges, and the means by which many people earn their living. Along with current waves of innovation in technology we also have an opportunity to reinvent the corporation and our business systems.

Third, we recognize that we don't have all the answers. So we call for more and better research on the economic and social implications of the digital revolution and increased efforts to develop long-term solutions that go beyond current thinking.

In summary, we believe that the digital revolution is delivering an unprecedented set of tools for bolstering growth and productivity, creating wealth, and improving the world. But we can create a society of shared prosperity only if we update our policies, organizations, and research to seize the opportunities and address the challenges these tools give rise to.

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Upfront

SARAH MAZZETTI

Apple Has Plans for Your DNA

The iPhone could become a new tool in genetic studies and a home for a new generation of apps related to health and well-being.

Of all the rumors ever to swirl around the world's most valuable company, this may be the first to involve spitting in a cup.

Apple is collaborating with researchers to help launch apps that would offer some iPhone owners the chance to get their DNA tested, according to people familiar with the plans.

Upfront

The apps are based on ResearchKit, a software platform Apple introduced in March that helps hospitals or scientists run studies on iPhones by collecting data from the devices' sensors or through surveys. The first five ResearchKit apps, including one called mPower that tracks symptoms of Parkinson's disease, recruited thousands of participants in a few days, demonstrating the reach of Apple's platform. "The obvious next thing is to collect DNA," says Gholson Lyon, a geneticist at Cold Spring Harbor Laboratory who isn't involved with the studies.

Nudging iPhone owners to submit DNA samples would thrust Apple's devices into a widening battle for genetic information. Universities, technology companies like Google, direct-to-consumer labs, and the U.S. government all hope to amass mega-databases of gene information to uncover clues about the causes of disease.

In two initial studies planned, Apple isn't going to directly collect or test DNA itself. That will be done by academic partners. The data would be maintained by scientists in a computing cloud, but certain findings could appear directly on consumers' iPhones as well. Someday you might swipe to share your genes as easily as you do your location.

An Apple spokeswoman declined to comment, but one person with knowledge of the plans said the company's eventual aim is to "enable the individual to show and share" DNA information with different recipients, including organizers of scientific studies. This person, like others with knowledge of the research, spoke on condition of anonymity because of the company's insistence on secrecy.

Apple began taking steps last year to make its devices indispensable for "digital health." Its latest version of the iOS operating system includes an app called Health, which has fields for more than 70 types of health data—everything from your weight to how many milligrams of manganese you eat (as yet, there's no field for your genome). Apple also entered a partnership with IBM to develop health apps for nurses and hospitals, as well as to mine medical data.

Apple's devices could be thrust into a widening battle for genetic information.

Now Apple is closely involved in shaping initial studies that will collect DNA. One, planned by the University of California, San Francisco, would study causes of premature birth by combining gene tests with other data collected on the phones of expectant mothers. A different study would be led by Mount Sinai Hospital in New York. Atul Butte, leader of the UCSF study and head of the Institute for Computational Health Sciences, notes that the genetic causes of premature birth aren't well understood. "I look forward to the day when we can get more sophisticated data than activity [from phones], like DNA or clinical data," he says.

To join one of the studies, a person would agree to have a gene test carried out—for instance, by returning a "spit kit" to a laboratory approved by Apple. The first such labs are said to be the advanced gene-sequencing centers operated by UCSF and Mount Sinai.

The planned DNA studies would look at 100 or fewer medically important disease genes (known as a "gene panel"), not a person's entire genome. These targeted tests, if done at large scale, would not cost more than a few hundred dollars each. Like the ResearchKit apps released so far, the studies would be approved by Apple and by an institutional review board, an oversight body that advises researchers on studies involving volunteers.

The ResearchKit program has been spearheaded by Stephen Friend, a one-time pharmaceutical company executive and now the head of Sage Bionetworks, a nonprofit that advocates for open scientific research. Friend, whom Apple describes as a medical technology advisor, envisions a data "commons" in which study subjects are active participants in

TO MARKET

Warehouse Help

Freight and Fetch

COMPANY:
Fetch Robotics

PRICE:
Not yet disclosed

AVAILABILITY:
In tests; wider release by 2016

One of these robots could reduce the strain on people who pick items off shelves in warehouses—while the other could grab items on its own. As workers walk around gathering things from shelves, they can toss them into a crate carried by the robot on the right, known as Freight. When an order is complete, a tap on a smartphone commands the robot to scoot the load off to its next destination. For certain picking jobs, Freight could instead be paired with the robot on the left, known as Fetch. Mounted on top of a wheeled base, it has a long, jointed arm with a gripper and a moving "head" with a depth camera. Freight and Fetch are likely to cost much less than human employees.

COURTESY OF FETCH ROBOTICS

scientific research. The problem, as he describes it, is that hospitals and research groups in the "medical-industrial complex" are notorious for hoarding data. In many cases they are legally bound to do so by state and federal privacy regulations. But no law stops individuals from sharing information about themselves. Thus one reason to "empower patients," as Silicon Valley rhetoric has it, is that if people collect their own data, or are given control of it, it could quickly find wide use in consumer apps and technologies, as well as in science.

One study that could get a boost is the Resilience Project, a joint undertaking by Sage and Mount Sinai to discover why some people are healthy even though their genes say they should have serious inherited diseases like cystic fibrosis. That project has scoured DNA data previously collected from more than 500,000 people, and as of last year it had identified about 20 such unusual cases. But the Resilience Project was having difficulty contacting those people because their DNA had been collected anonymously. By contrast, recruiting people through iPhone apps could make ongoing contact easy.

Someday you might swipe to share your genes as easily as you do your location.

By playing a role in gene studies, Apple would join a short list of organizations trying to excite people about what they might do with their own genetic information. Among them are the genealogy company Ancestry.com, the Open Humans Project, and 23andMe, a direct-to-consumer testing company that has collected DNA profiles of more than 900,000 people who bought its $99 spit kits.

That is one of the largest DNA data banks anywhere, but it took 23andMe nine years to reach those numbers. By comparison, Apple sold 60 million iPhones in just the first three months of this year, contributing to a total of about 750 million overall. DNA studies through ResearchKit could, theoretically, have rapid and immense reach.

But DNA data remains tricky to handle, and in some cases what people can be told about it is regulated by the U.S. Food and Drug Administration.

One study launched this year by the University of Michigan, Genes for Good, uses a Facebook app to recruit subjects and carry out detailed surveys about their health and habits. In that study, participants will be sent a spit kit and will later gain access to DNA information via a file they can download to their desktops.

So far about 4,200 people have signed up, says Gonçalo Abecasis, the geneticist running the research. Abecasis says that the project will tell people something about their ancestry but won't try to make health predictions. "There is tension in figuring out what is okay as part of our research study and what would be okay in terms of health care," he says. "You can imagine that a lot of people have a good idea how to interpret the DNA … but what is appropriate to disclose isn't clear."

One issue facing Apple is whether consumers are even interested in their DNA. So far, most people still have no real use for genetic data. Some people have ideas: imagine you could swipe your genes at a drugstore while filling a prescription, getting a warning if you're predicted to have a reaction to the drug. Or perhaps an app could calculate exactly how closely related you are to anyone else. But Lyon, the Cold Spring Harbor geneticist, believes that right now the story is mostly about helping researchers. "They need people to donate their DNA," he says. "One incentive is to have it on their phone where they can play with it." *—Antonio Regalado*

PING ZHU

3 QUESTIONS

Biz Stone

You start companies that help people communicate. Sometimes it works well, as with Twitter. Sometimes it doesn't, as with Jelly, which lets people ask questions with text and an image. How did Jelly lead to your latest venture, Super?
Three or four months into Jelly we just didn't see it becoming a global phenomenon. It wasn't fun enough. People were using it for homework, math problems. A lot of people were asking, "What kind of spider is this?" and I was like, do we really want to be the kings of spider identification? How can we make this way better? I said, we'll turn Q and A into A and Q. We'll [let people post an] answer, and the question is presumed.

Super users pick a brightly colored rectangle containing an all-caps phrase such as "THE BEST" or "THE WORST" and add their own message and photo. You say you want it to look as if it came from the conceptual artist Barbara Kruger. Why?
I just wanted it to look crazy and fun. She takes big black-and-white pictures and puts big red rectangles or squares with big white language that says things like "I shop therefore I am." They're meant to be incendiary. And that was the idea—let's channel people to be very emphatic.

You're an investor in the augmented-reality company Magic Leap. How might Super look in a virtual world?
I think my first pass at it would be to make it look like a museum—like you're walking around with all these walls and looking at these Supers. That would actually be kind of fun.
—Rachel Metz

Upfront

Write Better E-Mails

A startup analyzes online data about your message recipients so it can guide you on how to appeal to them.

It can be hard to figure out just what to say in an e-mail to someone you don't know very well. A startup wants to make this easier by correcting messages as you type, suggesting changes that may make any particular recipient more receptive to what you're saying.

The company's software, Crystal, attempts to show you the best and worst ways to converse with people, in messages and in person, by scrutinizing publicly available data from LinkedIn, Twitter, blogs, and other online sources. The startup lets users look up people's personality profiles on its website for free; for $19 per month, you can access a Gmail plug-in for the Chrome Web browser that offers specific real-time suggestions about word choice and punctuation, depending on whom you're writing to. A mobile app is also in the works.

While Crystal might sound creepy, at its core it's not all that different from what huge companies like Facebook and Netflix already do when mining your user data to figure out what ads to show you or movies to suggest. "I could see why people are put off at first, as a small segment of people are," says Crystal creator Drew D'Agostino. "They see it as an invasion of privacy, but it's just using public data."

If it can accurately depict people's personalities, it could be helpful for interactions ranging from sales and recruiting to dating. When you type in a name on Crystal's website, Crystal looks it up in a database of profiles based on data from social-media sites, the startup information site CrunchBase, and reviews written on Amazon.com. The service uses several algorithms to derive a personality score from what it finds, and matches that score with one of 54 personality types.

Then Crystal shows you the results—a quick personality summary, along with advice on how to speak to that person. It also provides a score to show how confident Crystal is that the results will be accurate (the more data it has about a person, the higher the confidence number). When I looked up Barack Obama, for example, Crystal deduced that the president is "friendly, casual, and extremely perceptive, 'connecting the dots' more quickly than others but occasionally rambling in conversation." It suggested that when I e-mail him, I use an emoticon and "appeal to his feelings to drive him to action."

I had Crystal's Gmail plug-in running as I wrote e-mails to co-workers and family members. It properly described my older brother as "ambitious, critical, and pragmatic" and my little brother as "persistent and results-driven," but like the characteristics associated with astrological signs, those descriptions could apply to a lot of people.

Crystal was more specific when it came to the e-mail text; for a note to one brother it suggested I cut a few characters from the subject line, predicting he wouldn't like a rambling header. It flagged my use of the word "basically" in a note to an editor, recommending I leave it out or "replace it with something like essentially or fundamentally." For another editor, it said I should avoid using two question marks in a row and cut the phrase "I'd love to." Instead, it said, I should say something more like "I want to."

That's good advice—essentially.

—Rachel Metz

PATRICK KYLE

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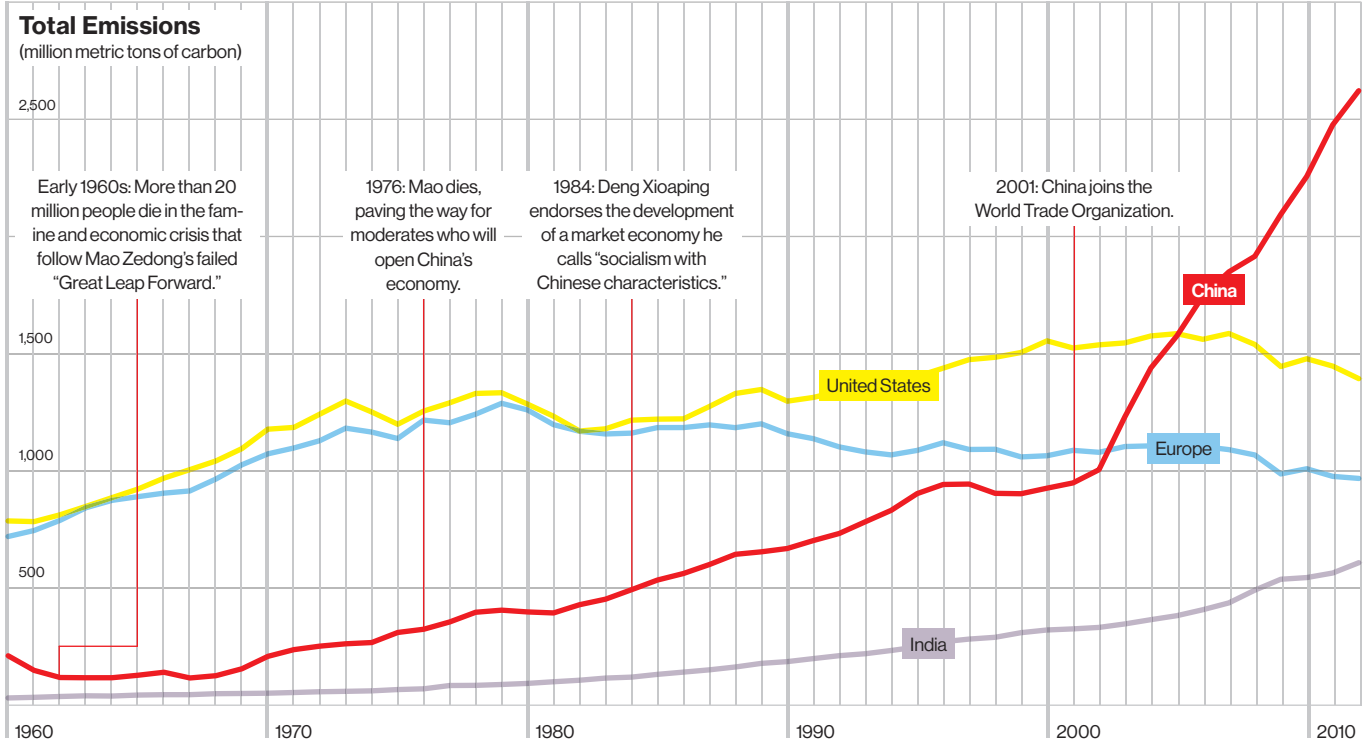
MIT Technology Review

Upfront

China's Climate Challenge

Rapid industrialization and rising standards of living have made China the world's top emitter of carbon dioxide (see "Fixing China's Coal Problem," page 22). Preventing a runaway increase will require the country to keep per capita emissions at a relatively low level.

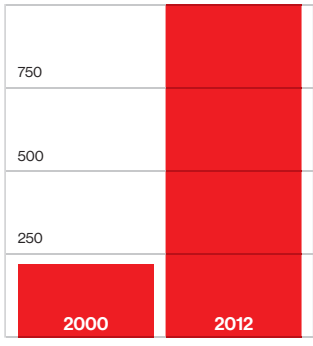


Role of Renewables

China generates about five times as much solar, wind, and hydroelectric power as it did in 2000. Even so, it has not substantially altered the overall makeup of its electricity supply. Nuclear's share has also held steady, at around 2 percent.

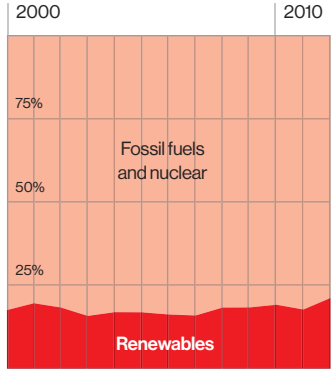
Total Generation

in billion kilowatt-hours



Overall Contribution

by percentage of total electric supply



Emissions per Capita

If you divide emissions by the number of people in the country, China's output is now higher than average but still well below that of the United States.

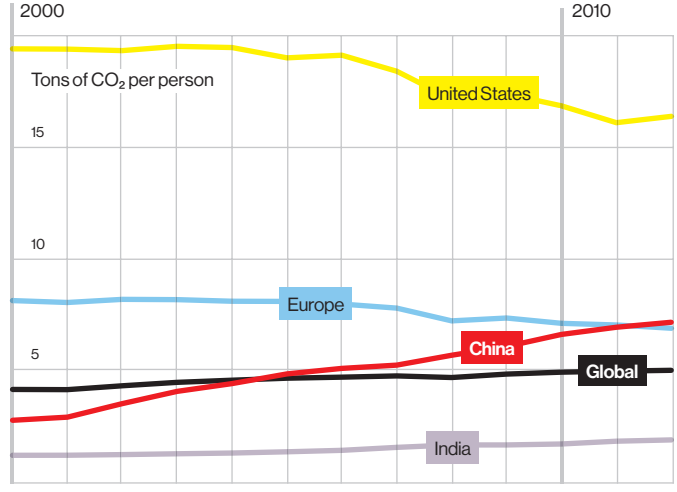


ILLUSTRATION BY LUKE SHUMAN
DATA FROM WORLD BANK AND THE GLOBAL CARBON PROJECT

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EmTech MIT is an opportunity to discover future trends and begin to understand the technologies that will drive the global economy. It's where technology, business, and culture converge, and where you gain access to the world's most innovative people and companies.

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Rethinking Nuclear Power

Julia Greer
Professor of Materials Science and Mechanics, California Institute of Technology
10 Breakthrough Technologies 2015: Nano-Architecture

Jeff Hammerbacher
Founder and Chief Scientist, Cloudera
A New Era of Innovation in Big Data

Christopher Soghoian,
Principal Technologist, ACLU
Privacy and Security in the Digital Age

Robert Wood
Charles River Professor of Engineering and Applied Sciences, Harvard University; Faculty Member, Wyss Institute
Robots Among Us

Upfront

QUOTED

"I look at this as one of the biggest changes that is happening to surgery."

—Glenn Green, a doctor in Michigan who saved the lives of three infants by propping their airways open with tiny stents custom-made on a 3-D printer.

"Eventually, they'll be able to make gumbo."

—Cynthia Matuszek, a robotics researcher at the University of Maryland, Baltimore, who suggests it will take decades for home robots to do physical work and not merely assist with online services, as consumer devices such as Jibo and Echo do now.

"We don't really know what we're made of."

—Aviv Regev, a computational biologist at the Broad Institute in Cambridge, Massachusetts, who is finding new types of cells thanks in part to advances in genomics.

BY THE NUMBERS

3.8 million
Computer- and mathematics-related jobs in the United States in 2014.

2.9 million
The same figure in 2000.

8 percent
The estimated annual decrease in the cost of battery packs used by top electric-car makers.

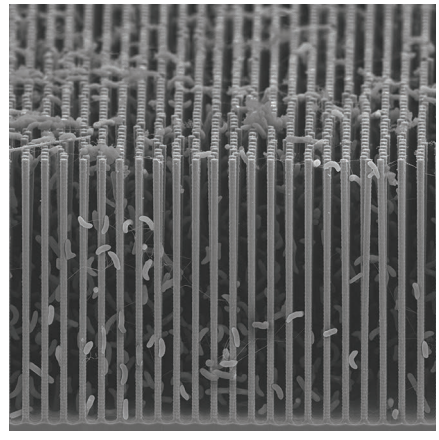
$99.5 billion
Worldwide investment in wind power in 2014, up 11 percent from the previous year.

96 percent
The portion of the world's smartphones that run an operating system made by Apple or Google.

Making Fuel from Sunlight

Researchers who put bacteria on nanoscale semiconductors discover a promising path toward efficient artificial photosynthesis.

Researchers at the University of California, Berkeley, say that by combining nanoscale materials with bacteria, they have opened the door to a new way of efficiently turning carbon dioxide, water, and sunlight into useful organic compounds—similar to what plants do through photosynthesis. Down the road, the researchers say, the system could become a commercially viable way to produce chemicals like drug precursors used by the pharmaceutical industry, or to store renewable energy in the form of liquid fuels.



These bacteria nestled in nanowires use electricity to produce valuable chemicals.

The goal of highly efficient artificial photosynthesis is a long-standing one, and there are many approaches to the problem, all of which face scientific hurdles. One general approach is to rely on microörganisms called electrotrophs, which can be coaxed, through the application of electricity, to make certain chemical building blocks.

To generate that electricity, some researchers have relied on bulky solar panels. In contrast, the new system works on a much smaller scale. The researchers nestled electrotrophic bacteria into semiconducting nanowires that are capable of both capturing solar energy and transmitting electricity to the microbes. The electrotrophs use the electrons to turn carbon dioxide and water into useful chemical building blocks. Those are then passed to genetically engineered *E. coli*, which in turn make a wide range of products.

This is the first working example of such a direct interface between bacteria and semiconducting materials for artificial photosynthesis, says Peidong Yang, a professor of chemistry and materials science at Berkeley and an inventor of the system. He and his colleagues demonstrated that the system could make butanol, a polymer used in biodegradable plastics, and three pharmaceutical precursors. It could in principle be used to make many other products, including chemicals that are valuable in relatively small volumes—unlike fuel, which must be produced at a very large scale to be economical.

The new system is about as efficient as natural photosynthesis at using the energy in sunlight, says Yang. That's not enough for the process to be commercially viable, but he says new semiconductor materials his group is working with should make the process more competitive.

Even then, a huge hurdle will remain: the bacteria must be kept alive, and at best they don't live very long. Yang says his team's ultimate goal is to develop a synthetic catalyst that could replace the bugs and work in concert with the semiconductors. *—Mike Orcutt*

COURTESY OF PEIDONG YANG

Leslie Dewan
Cofounder and CEO
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ROMAN MURADOV

Fixing China's Coal Problem

The country has rapidly cleaned up its coal plants. Now comes the hard part.

When William Latta first came to China, in 2005, he intended to look for companies to acquire for the French power giant Alstom. He wound up creating his own. "I believed we could do something about China's pollution problem, and create a profitable business doing it," he says.

The company that Latta founded, LP Amina, uses ammonia derivatives called amines to reduce pollution from coal plants' smokestacks, particularly sulfur oxides and nitrogen oxides. It joined an array of companies in a program critical to the future of the world: cleaning up China's vast and dirty coal industry.

It's an urgent task. China burns about as much coal every year as the rest of the world combined. According to a study first published in *The Lancet*, 1.2 million people die prematurely every year from air pollution in China. Giant coal mines have ravaged millions of square miles of China's interior.

That is not news. What's less widely understood is that companies like LP Amina have largely succeeded, and the government's drive to rein in air pollution from coal plants is making progress. Pollution levels in many of China's major cities fell from 2013 to 2014, according to Greenpeace, and dropped nearly another one-third in the first quarter of 2015. Levels of the particulates that contribute to emphysema and other respiratory diseases fell by 31 percent in Hebei Province, which includes Beijing, according to government figures collected by the environmental group. The skies over Beijing, Shanghai, and Shenzhen are not exactly blue, but they are getting less gray. According to some estimates, close to 90 percent of the coal plants in China now have basic pollution controls.

That's a major environmental achievement. But it leaves behind a deeper challenge: greenhouse gases, which are unaffected by widely available pollution-control technologies. "The big question now is, what happens on CO_2?" asks Latta.

The significance of that question becomes apparent when you tour the coal industry in Shanxi Province, in northern China near the border with Inner Mongolia. There, below ridgelines traced by remnants of the Great Wall, hundreds of small coal mines still supply gigantic power plants that belch millions of tons of carbon dioxide into the atmosphere every year. The central government's program to shut down coal plants near the coast has done little about those in the interior. In fact, the coal industry in the west and north is set for dramatic expansion over the next decade.

This will coincide with a huge push to handle coal differently: to convert it into synthetic natural gas, or syngas. Made up of hydrogen, carbon monoxide, and carbon dioxide, syngas can be burned to produce electricity or converted into petrochemicals. What's promising from an environmental standpoint is that the carbon can be captured and removed before

the gas is processed, although syngas plants generally don't do this now.

The government plans dozens of coal gasification plants across Inner Mongolia and Shanxi and Xinjiang Provinces; they are expected to supply liquid fuel for vehicles, ethylene for petrochemical plants, and other products. According to the National Energy Administration, production will reach 50 billion cubic meters of syngas a year by 2020. That would be 25 times more than 2014 production.

Government support, along with rising demand for syngas derivatives, drove a land rush starting in 2005 as state-owned enterprises broke ground on expansive and hastily conceived coal-to-gas plants. That initial boom was an "epic failure," according to Bobby Wang, the product marketing leader for gasification at GE Power & Water in China. The early plants were dirty and produced syngas for which there was virtually no market, mainly because of a lack of pipeline networks.

The frenzy has given way to a more measured approach. Now Chinese coal suppliers have formed joint ventures with GE and smaller U.S. companies, such as LP Amina, Synthesis Energy Systems, and Summit Power, to build financially viable plants intended to supply syngas for power generation, petrochemicals, heat for industrial processes, and more. Eventually the boilers to produce electricity in these plants will use integrated gasification combined-cycle (IGCC) technology, the most efficient way to gasify and burn coal. Once these state-of-the-art gasifiers are "unlocking the hydrocarbons" from mineral coal, says Jason Crew, CEO of Seattle-based Summit Power, "you can do all sorts of things, including clean up the carbon."

Close to 90 percent of the coal plants in China now have basic pollution controls.

How well that last part works is due for a big test, not in Inner Mongolia but in the West Texas oil patch. Supported by a $450 million grant from the U.S. Department of Energy, the Texas Clean Energy Project would combine a 400-megawatt IGCC plant with a facility that produces urea for fertilizer, plus a system that would remove 90 percent of the carbon dioxide produced and use it to enhance oil recovery in the wells of the Permian Basin. Along with Summit Power, the participating companies include Siemens and a unit of the China National Petroleum Corporation. Projected to cost more than $1.7 billion, the Texas project would be the most advanced coal plant ever built.

However, even if that project succeeds, capturing carbon dioxide will be economically viable in only a few locations where there's demand for the gas. That's largely why most carbon-capture projects for coal plants have stalled or been abandoned. Ultimately, the likeliest way for China to continue its progress on coal pollution may be simply to burn less of it.

Remarkably, thanks to a slowing economy, a shift toward less energy-intensive industries, and a crackdown on small, unlicensed coal burners, coal consumption in China fell nearly 2 percent in 2014, according to the Institute for Energy Economics and Financial Analysis, even as the economy grew by 7.4 percent. A Greenpeace report released in May found that coal consumption fell 8 percent in the first four months of 2015 compared with the same period a year before. If that trend continues for the full year, it would represent "the largest recorded year-on-year reduction in coal use and CO_2 in any country." As the U.S. shale gas revolution shows, dramatic swings in energy production can happen suddenly and unexpectedly. Pouring billions into futuristic clean coal plants may wind up looking, to future energy historians, like throwing good money after bad. *—Richard Martin*

TO MARKET

Off the Grid

Powerwall

COMPANY:
Tesla Motors

PRICE:
$3,000 for seven kilowatt-hours or $3,500 for 10

AVAILABILITY:
Summer

COURTESY OF TESLA

Expanding beyond electric vehicles, Tesla Motors will sell stationary batteries that let homes and businesses store the surplus solar power they generate during the day. The larger of the two battery models should keep an average-size home running for a day. Tesla is launching this business partly because it's already making vehicle batteries and can benefit from the economies of scale that come from producing both types. Another reason is that the market for energy storage is expected to grow in concert with the use of solar power. Tesla needs both electric vehicles and solar power to boom if it hopes to use the projected output from a $5 billion battery "gigafactory" it's building in Nevada.

LEMELSON-MIT
Celebrating invention, inspiring youth

THE LEMELSON-MIT PROGRAM:

Two Decades of Celebrating Invention and Inspiring Youth

The Lemelson-MIT Program has been changing the lives of talented inventors, scientists, and engineers for 20 years – and these people, in turn, have changed the world.

Founded at MIT in 1994 by engineer Jerome H. Lemelson – a prolific inventor who held more than 600 patents – and his wife, Dorothy, the program celebrates outstanding inventors and inspires young people to pursue creative lives and careers through invention. "My husband, Jerry, believed that we needed to invest in the ingenuity and inventiveness of our country's youth to expand our economy and maintain our economic competitiveness in a constantly changing world," says Dorothy Lemelson, chair of The Lemelson Foundation. The program officially marked its 20th anniversary during its annual EurekaFest celebration at MIT in June.

The program, funded by the Portland, Oregon-based Lemelson Foundation and administered by MIT's School of Engineering, has honored several dozen professional and student inventors. It has presented 20 inventors with the annual $500,000 Lemelson-MIT Prize and annually presented prizes of $10,000 to $30,000 to collegiate inventors. The program recently introduced prizes for graduate and undergraduate students across the nation and new initiatives for younger inventors.

The program has also presented Lifetime Achievement Awards to 13 inventors and to seven innovators for their contributions to sustainability and global innovation.

Lemelson, who passed away in 1997, spoke frequently about the importance of introducing young people to invention early in life, proving to them "that invention can bring rewards far greater than they can imagine." To that end, the program has awarded grants of up to $10,000 to nearly 200 InvenTeams – teams of high school students and their educators – since 2003, all to empower and encourage students to invent. The program launched JV InvenTeams in 2014 for high school freshmen and sophomores who lack access to enrichment opportunities in science, technology, engineering, and math (STEM). The goal: to cultivate students' inventive curiosity and help them develop hands-on skills, as well as support their educators.

Following are examples of how both midcareer and collegiate Lemelson-MIT awards have made a difference in the recipients' lives – and how those inventors have gone on to positively impact the lives of many other people.

Sangeeta Bhatia, a biomedical engineer, physician, and MIT researcher and professor, received the Lemelson-MIT Prize in recognition of her work in designing and commercializing miniature technologies to improve human health and patient care on a global scale. Her portfolio of inventions addresses complex problems in areas such as drug toxicity, tissue regeneration, cancer therapeutics, noninvasive diagnostics, and infectious diseases. She and her trainees have launched 10 companies offering more than 70 products, and she holds more than 40 issued or pending patents.

The Lemelson-MIT Prize has generated enormous support and visibility for the group Bhatia oversees as director of the Laboratory for Multiscale Regenerative Technologies at MIT's Koch Institute for Integrative Cancer Research. "This has helped advance our work in inventing for human health by spawning new collaborations, generating excitement and funding for a new startup to translate a novel diagnostic to the clinic, and attracting top talent from around the world," Bhatia says.

The prize came with tremendous personal benefits as well. Earlier in her career, Bhatia always felt somewhat fragmented: "part engineer, part physician, part scientist, part mentor, part teacher, part entrepreneur," as she puts it. "The Lemelson-MIT Prize helped me to recognize myself simply as an inventor, to collect all these identities in one cohesive vision."

Bhatia received a PhD in biomedical engineering from MIT and an MD from Harvard.

Sangeeta Bhatia *(center)*
Lemelson-MIT Prize, 2014

Stephen Quake
Lemelson-MIT Prize, 2012

Nate Ball
Lemelson-MIT Student Prize, 2007

David Sengeh
Lemelson-MIT "Cure it!" Graduate Winner, 2014

Stephen Quake, a professor of bioengineering at Stanford University, received the Lemelson-MIT Prize for biomedical discoveries and commercialization of inventions that are revolutionizing human health. The prize recognized Quake's work in personalized medicine, drug discovery, genome analysis, and noninvasive diagnostics.

Personal experience often inspires Quake's inventions. He became concerned about the potential damage posed by prenatal testing as an expectant father and created the first noninvasive prenatal test for Down syndrome. He then pioneered research that helps scientists conduct research through high-throughput sequencing after his daughter was diagnosed with food allergies. Quake has cofounded two companies to commercialize those inventions, founded two other businesses, and received more than 80 patents.

The Lemelson-MIT Prize has enhanced Quake's research. "Many colleagues with ideas or inventions now seek me out for assistance in how to realize them," says Quake, who received a bachelor's degree in physics and master's degree in math from Stanford and a doctorate in theoretical physics from Oxford University. "Often, these are related to health care, and it is very satisfying to work on things that improve people's lives."

One night on his way to a lab for some late-night research, **Nate Ball** – then an MIT student and national collegiate pole-vaulting champion – received a call he will never forget. He learned that he'd won the Lemelson-MIT Student Prize, then a $30,000 award presented annually to one student at MIT.

"Suddenly, I was on a world stage," Ball remembers. "It didn't change the goals of my work, but the motivation was multiplied tenfold. People reached out to me from all over. It was a wonderful discovery to find how many people were inspired not just by my specific work, but by the process of invention itself."

Ball was honored primarily for his work on a powered rope ascender. This portable device, which relies on a rope-handling mechanism developed by Ball, can lift more than 250 pounds at 10 feet per second, providing new climbing capabilities for rescuers, emergency personnel, and soldiers. Ball founded Atlas Devices with three fellow mechanical-engineering students to develop and commercialize the device.

"Winning the student prize enabled my embarking full-tilt on the career I feel so fortunate to pursue," he says. "I wouldn't be where I am without it."

David Sengeh, an MIT PhD candidate in biomedical engineering, grew up in Sierra Leone during that nation's bloody 11-year war, when rebel forces often amputated citizens' limbs as part of a terror campaign. After the war, Sengeh saw many people he knew struggle with painful, ill-fitting prostheses. Even in the United States, many amputees suffer pressure sores and deep tissue injury from prosthetic devices.

Sengeh hopes to change that with the next-generation prosthetic devices he's designing and building – an effort for which he received the $15,000 Lemelson-MIT "Cure it!" Graduate Prize in 2014. His process uses magnetic resonance imaging and computer-aided design to create a mathematical model of a particular patient's prosthesis, from which the actual prosthetic interface, or socket, is then created via 3-D printing. The result is a better-fitting prosthesis that's also highly cost-effective.

Sengeh received a bachelor's degree in engineering from Harvard and a master's in media arts and science from MIT.

Asked about the award's impact on his life, Sengeh replies: "I never imagined I could win the Lemelson-MIT Student Prize. Winning it inspired me to do more. I feel tremendously fortunate and constantly humbled by my peers, and I have a renewed sense of curiosity."

Meanwhile, the Lemelson-MIT Program's emphasis on community engagement and youth initiatives will continue to inspire inventors to collaborate on solutions to problems "larger than any one of us could ever attempt solving alone," Sengeh says.

"The program began by recognizing career inventors," notes Michael J. Cima, David H. Koch professor of engineering and faculty director of the Lemelson-MIT Program. "What we learned when we tried to measure the impact of these prizes is that we wanted to have examples of younger inventors to act as role models. Now where we're going is to impact not only students, but educators who can continue the process of mentoring young people in invention in these open-ended problems."

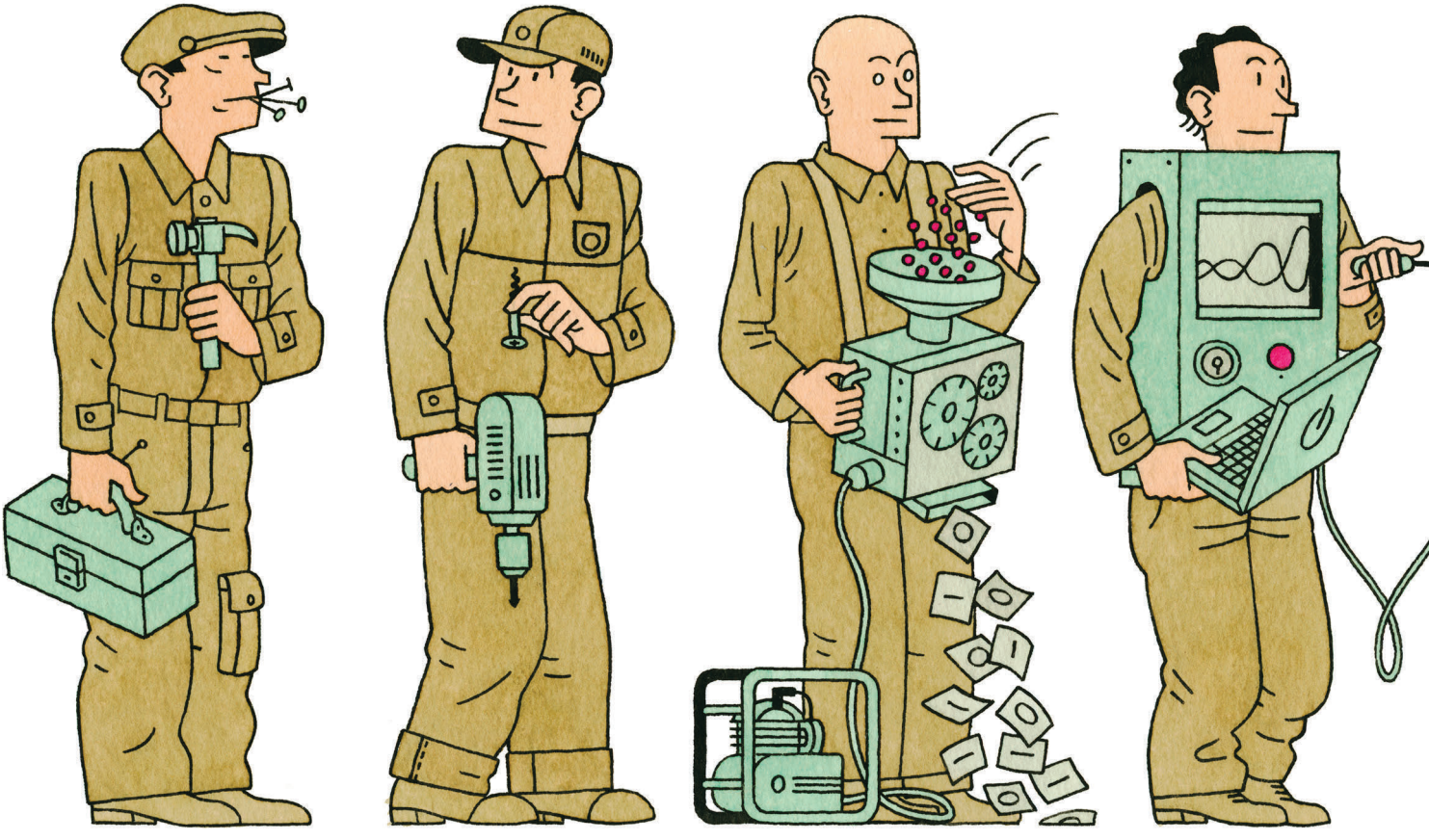
For applications or nominations for Lemelson-MIT Program awards, email awards-lemelson@mit.edu or visit lemelson.mit.edu, where you'll also find a special report on the Program's 20th anniversary.

Who Will Own the Robots?

We're in the midst of a jobs crisis, and rapid advances in AI and other technologies may be one culprit. How can we get better at sharing the wealth that technology creates?

By David Rotman

The way Hod Lipson describes his Creative Machines Lab captures his ambitions: "We are interested in robots that create and are creative." Lipson, an engineering professor at Cornell University (this July he's moving his lab to Columbia University), is one of the world's leading experts on artificial intelligence and robotics. His research projects provide a peek into the intriguing possibilities of machines and automation, from robots that "evolve" to ones that assemble themselves out of basic building blocks. (His Cornell colleagues are building robots that can serve as baristas and kitchen help.) A few years ago, Lipson demonstrated an algorithm that explained experimental data by formulating new scientific laws, which were consistent with ones known to be true. He had automated scientific discovery.

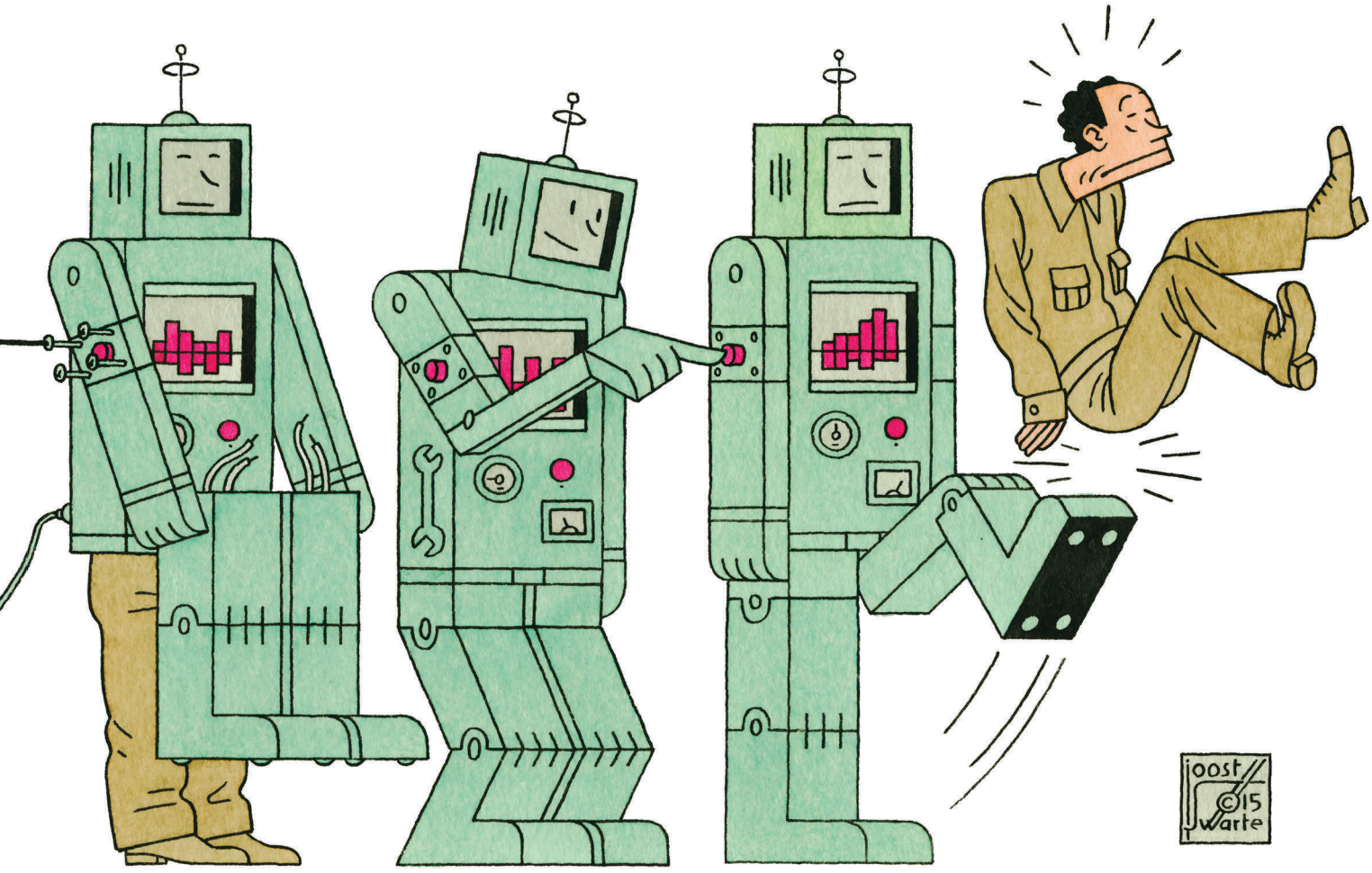


Illustrations by Joost Swarte

Lipson's vision of the future is one in which machines and software possess abilities that were unthinkable until recently. But he has begun worrying about something else that would have been unimaginable to him a few years ago. Could the rapid advances in automation and digital technology provoke social upheaval by eliminating the livelihoods of many people, even as they produce great wealth for others?

"More and more computer-guided automation is creeping into everything from manufacturing to decision making," says Lipson. In the last two years alone, he says, the development of so-called deep learning has triggered a revolution in artificial intelligence, and 3-D printing has begun to change industrial production processes. "For a long time the common understanding was that technology was destroying jobs but also creating new and better ones," says Lipson. "Now the evidence is that technology is destroying jobs and indeed creating new and better ones but also fewer ones. It is something we as technologists need to start thinking about."

Worries that rapidly advancing technologies will destroy jobs date back at least to the early 19th century, during the Industrial Revolution in England. In 1821, a few years after the Luddite protests, the British economist David Ricardo fretted about the "substitution of machinery for human labour." And in 1930, during the height of the worldwide depression, John Maynard Keynes famously warned about "technological unemployment" caused by "our discovery of means of economising the use of labour." (Keynes, however, quickly added that "this is only a temporary phase of maladjustment.")



Now, technology is once again under suspicion as rising income inequality confronts the United States, Europe, and much of the rest of the developed world. A recent report from the Organization for Economic Cooperation and Development concluded that the gap between the rich and poor is at a historically high level in many of its 34 member countries, driven largely by a drop in earning power for the bottom 40 percent of the population. Many of the lowest earners have seen wages decrease over the last few decades, and the OECD warns that income inequality is now undermining economic growth.

Meanwhile, the erosion of the American middle class and the pressure on the lowest-paid U.S. workers has been painfully evident for years. Only 68 percent of men between 30 and 45 who have a high school diploma were working full time in 2013, according to a recent report by the Hamilton Project at the Brookings Institution, a Washington-based public-policy group. Earnings for the typical worker haven't kept up with the growth of the economy for decades. Median earnings for a man without a high school diploma fell 20 percent from 1990 to 2013, while wages for those with only a high school diploma dropped 13 percent. Women have fared somewhat better, though they still generally earn less than men. Over the same period, earnings for women without a high school diploma dropped 12 percent, while earnings for those with a high school diploma actually rose by 3 percent.

Do today's rapid advances in artificial intelligence and automation portend a future in which robots and software greatly reduce the need for human workers?

It is notoriously hard to determine the factors that go into job creation and earnings, and it is particularly difficult to isolate the specific impact of technology from that of, say, globalization, economic growth, access to education, and tax policies. But advances in technology offer one plausible, albeit partial, explanation for the decline of the middle class. A prevailing view among economists is that many people simply don't have the training and education required for the increasing number of well-paying jobs requiring sophisticated technology skills. At the same time, software and digital technologies have displaced many types of jobs involving routine tasks such as those in accounting, payroll, and clerical work, forcing many of those workers to take more poorly paid positions or simply abandon the workforce. Add to that the increasing automation of manufacturing, which has eliminated many middle-class jobs over the past decades, and you begin to see why much of the workforce is feeling squeezed.

These are long-term trends that began decades ago, says David Autor, an MIT economist who has studied "job polarization"—the disappearance of middle-skill jobs even as demand increases for low-paying manual work on the one hand and highly skilled work on the other. This "hollowing out" of the middle of the workforce, he says, "has been going on for a while."

Nevertheless, the recession of 2007–2009 may have sped up the destruction of many relatively well-paid jobs requiring repetitive tasks that can be automated. These so-called routine jobs "fell off a cliff in the recession," says Henry Siu, an economist at the University of British Columbia, "and there's been no large rebound." This type of work, which includes white-collar jobs in sales and administration as well as blue-collar jobs in assembly work and machine operation, makes up about 50 percent of employment in the United States. Siu's research also shows that the disappearance of these jobs has most harshly affected people in their 20s, many of whom seem to have simply stopped looking for work.

That's bad enough. But there's an even more fundamental fear. Is this a harbinger of what's to come for other sectors of the workforce, as technology takes over more and more of the jobs that have long been considered secure paths to a middle-class life? Are we at the beginning of an economic transformation that is unique in history, wonderful for what it could do in bringing us better medicine, services, and products, but devastating for those not in a position to reap the financial benefits? Will robots and software replace most human workers?

Scaring children

No one knows the answer. Many economists see little convincing evidence that advances in technology will be responsible for a net decrease in the number of jobs, or that what we're undergoing is any different from earlier transitions when technology destroyed some jobs but improved employment opportunities over time. Still, over the last several years, a number of books and articles have argued that the recent advances in artificial intelligence and automation are inherently different from past technological breakthroughs in what they portend for the future of employment. Martin Ford is one of those who think this time *is* different. In his new book, *Rise*

Automation Angst

Rise of the Robots: Technology and the Threat of a Jobless Future
by Martin Ford
Basic Books, 2015

The Great Divide: Unequal Societies and What We Can Do About Them
by Joseph E. Stiglitz
W.W. Norton, 2015

Inequality: What Can Be Done?
by Anthony B. Atkinson
Harvard University Press, 2015

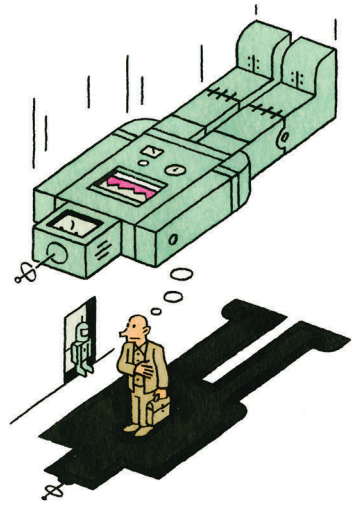
The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies
by Erik Brynjolfsson and Andrew McAfee
W.W. Norton, 2014

of the Robots: Technology and the Threat of a Jobless Future, Ford points to numerous examples of new technologies, such as driverless cars and 3-D printing, that he thinks will indeed eventually replace most workers. How then will we adapt to this "jobless future"?

Ford recommends a guaranteed basic income as part of the answer. Simply put, his prescription is to give people a modest amount of money. It's not a new idea. One version of it, called a negative income tax, was popularized by the conservative economist Milton Friedman during the early 1960s as a way to replace some of the growing government bureaucracy. And Ford quotes the economist Friedrich Hayek, who in 1979 described assuring a minimum income as a way to provide "a sort of floor below which nobody need fall even when he is unable to provide for himself." Both Richard Nixon and his 1972 presidential rival George McGovern, a liberal Democrat, championed some form of the policy.

The idea went out of fashion in the 1980s, but it has returned in recent years as a way to help those people shut out of the labor markets. In the libertarian version, it's a way to provide a safety net with minimum government involvement; in the progressive version, it supplements other programs to help the poor.

Whether it is good politics or good social policy has been endlessly debated. Recently, others have suggested a related policy: expanding the Earned Income Tax Credit, which would give some extra money to low-paid workers. These ideas probably do make sense as a way to strengthen the social safety net. But if you believe that the rapid advance of technology could eliminate the need for most workers, such policies do little to directly address that scenario. Allowing a large number of workers to become irrelevant in the technology-centric economy would be a huge waste of human talent and ambition—and would probably put an enormous financial burden on society. What's more, a guaranteed basic income does not offer much to those in the middle class whose jobs are at risk, or to those who have recently fallen from financial security in the absence of well-paying jobs.



It might also be premature to plan for a dystopian future of hardly any jobs. Ford's *Rise of the Robots* offers many examples of impressive achievements in automation, software, and AI that could make some jobs obsolete—even those requiring highly trained professionals in fields like radiology and law. But how do you assess just how specific technologies like these will affect the total number of jobs in the economy?

In fact, there is not much evidence on how even today's automation is affecting employment. Guy Michaels and his colleague Georg Graetz at the London School of Economics recently looked at the impact of industrial robots on manufacturing in 17 developed countries. The findings tell a mixed story: the robots did seem to replace some low-skill jobs, but their most important impact was to significantly increase the productivity of the factories, creating new jobs for other workers. Overall, there was no evidence that the robots reduced total employment, says Michaels.

If it's difficult to quantify the effect of today's technology on job creation, it's impossible to accurately predict the effects of future advances. That opens the door to wild speculation. Take an extreme example raised by Ford: molecular manufacturing. As proposed by some nanotechnology boosters, most notably the author K. Eric Drexler, the idea is that one day it will be possible to build almost anything with nanoscale robots that move atoms around like tiny building blocks. Though Ford acknowledges that it might not happen, he warns that jobs will be devastated if it does.

The credence Ford gives to Drexler's vision of nanobots slaving away in molecular factories seems less than warranted, though, given that the idea was debunked by the Nobel-winning chemist Richard Smalley more than a decade ago (see "Will the Real Nanotech Please Stand Up?" March/April 1999). Smalley saw great potential for nanotech in areas such as clean energy, but his objection to molecular

manufacturing as Drexler described it was simple: it ignores the rules of chemistry and physics governing the way atoms bind and react with each other. Smalley admonished Drexler: "You and people around you have scared our children. I don't expect you to stop, but … while our future in the real world will be challenging and there are real risks, there will be no such monster as the self-replicating mechanical nanobot of your dreams."

Though Ford does note Smalley's criticism, one begins to wonder whether his conjuring the "rise of the robots" might not indeed be needlessly scaring our children. Speculating about such far-fetched possibilities is a distraction in thinking about how to address future concerns, much less existing job woes.

A more realistic, but in its way more interesting, version of the future is being written in the downtown Chicago offices of Narrative Science. Its software, called Quill, is able to take data—say, the box score of a baseball game or a company's annual report—and not only summarize the content but extract a "narrative" from it. Already, *Forbes* is using it to create some stories about corporate earnings, and the Associated Press is using a rival's product to write some sports stories. The quality is readable and is likely to improve greatly in coming years.

Yet despite the potential of such technology, it is not clear how it would affect employment. "As AI stands today, we've not seen a massive impact on white-collar jobs," says Kristian Hammond, a Northwestern University computer scientist who helped create the software behind Quill and is a cofounder of the company. "Short-term and medium-term, [AI] will displace work but not necessarily jobs," he says. If AI tools do some of the scut work involved in analyzing data, he says, people can be "free to work at the top of their game."

And as impressive as Quill and other recent advances are, Hammond is not yet convinced that the capabilities of general-purpose AI are poised for great expansion. The current resurgence in the field, he says, is being driven by access to massive amounts of data that can be quickly analyzed and by the immense increase in computing power over what was available a few years ago. The results are striking, but the techniques, including some aspects of the natural-language generation methods that Quill employs, make use of existing technologies empowered by big data, not breakthroughs in AI. Hammond says some recent descriptions of certain AI programs as black boxes that teach themselves capabilities sound more like "magical rhetoric" than realistic explanations of the technology. And it remains uncertain, he adds, whether deep learning and other recent advances will truly "work as well as touted."

> "Short-term and medium-term, [AI] will displace work but not necessarily jobs."

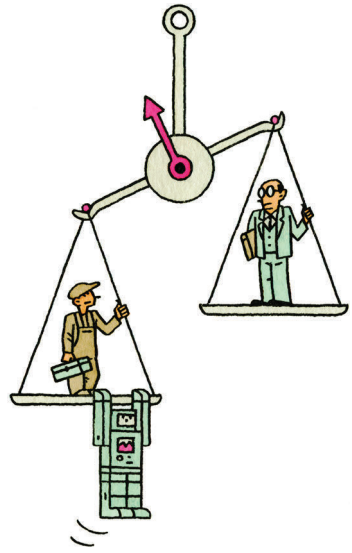
In other words, it would be smart to temper our expectations about the future possibilities of machine intelligence.

The gods of technology

"Too often technology is discussed as if it has come from another planet and has just arrived on Earth," says Anthony Atkinson, a fellow of Nuffield College at the University of Oxford and a professor at the London School of Economics. But the trajectory of technological progress is not inevitable,

he says: rather, it depends on choices by governments, consumers, and businesses as they decide which technologies get researched and commercialized and how they are used.

Atkinson has been studying income inequality since the late 1960s, a period when it was generally a subject on the back burner of mainstream economics. Over those years, income inequality has grown dramatically in a number of countries. Its levels rose in the U.K. in the 1980s and have not fallen since, and in the United States they are still rising, reaching historically unprecedented heights. The publication last year of his frequent collaborator Thomas Piketty's remarkably successful *Capital in the 21st Century* made inequality the hottest topic in economics. Now Atkinson's new book, called *Inequality: What Can Be Done?*, proposes some solutions. First on his list: "encouraging innovation in a form that increases the employability of workers."



When governments choose what research to fund and when businesses decide what technologies to use, they are inevitably influencing jobs and income distribution, says Atkinson. It's not easy to see a practical mechanism for picking technologies that favor a future in which more people have better jobs. But "at least we need to ask" how these decisions will affect employment, he says. "It's a first step. It might not change the decision, but we will be aware of what is happening and don't have to wait until we say, 'Oh dear, people have lost their jobs.'"

Part of the strategy could emerge from how we think about productivity and what we actually want from machines. Economists traditionally define productivity in terms of output given a certain amount of labor and capital. As machines and software—capital—become ever cheaper and more capable, it makes sense to use less and less human labor. That's why the prominent Columbia University economist Jeffrey Sachs recently predicted that robots and automation would soon take over at Starbucks. But there are good reasons to believe that Sachs could be wrong. The success of Starbucks has never been about getting coffee more cheaply or efficiently. Consumers often prefer people and the services humans provide.

Take the hugely popular Apple stores, says Tim O'Reilly, the founder of O'Reilly Media. Staffed by countless swarming employees armed with iPads and iPhones, the stores provide a compelling alternative to a future of robo-retail; they suggest that automating services is not necessarily the endgame of today's technology. "It's really true that technology will take away a class of jobs," says O'Reilly. "But there is a choice in how we use technology."

In that sense, Apple stores have found a winning strategy by not following the conventional logic of using automation to lower labor costs. Instead, the company has cleverly deployed an army of tech-savvy sales employees toting digital gadgets to offer a novel shopping experience and to profitably expand its business.

O'Reilly also points to the enormous success of the car service Uber. By using technology to create a convenient and efficient reservation and payment service, it has created a robust market. And in doing so, it has expanded the demand for drivers—who, with the aid of a smartphone and app, now have greater opportunities than they might working for a conventional taxi service.

The lesson is that if advances in technology are playing a role in increasing inequality, the effects are not inevitable, and they can be altered by government, business, and consumer decisions. As the economist Paul Krugman recently told an audience at a forum called "Globalization, Technological Change, and Inequality" in New York City, "A lot of what's happening [in income inequality] is not just the gods of technology telling us what must happen but is in fact [due to] social constructs that could be different."

Who owns the robots?

The effects of automation and digital technology on today's employment picture are sometimes downplayed by those who point to earlier technology transitions. But that ignores the suffering and upheaval during those periods. Wages in England were stagnant or fell for around 40 years after the beginning of the Industrial Revolution, and the misery of factory workers is well documented in the literature and political writings of the day.

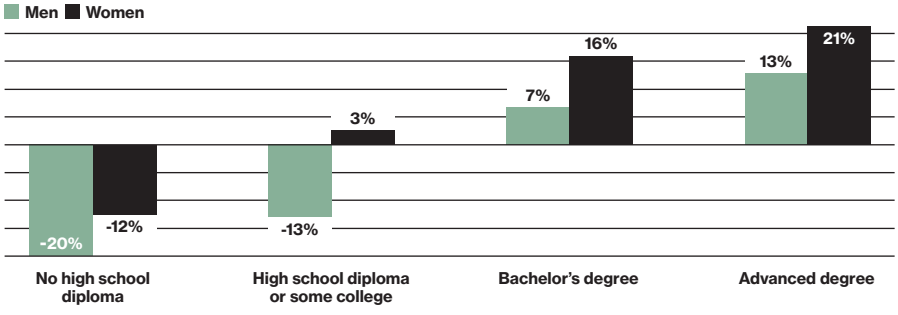
In his new book, *The Great Divide*, the Columbia University economist Joseph Stiglitz suggests that the Great Depression, too, can be traced to technological change: he says its underlying cause was not, as is typically argued, disastrous government financial policies and a broken banking system but the shift from an agricultural economy to a manufacturing one. Stiglitz describes how the advent of mechanization and

Disappearing Jobs

Automation and digital technology have replaced many jobs involving repetitive tasks in manufacturing and office work. The remaining jobs often require increasingly advanced skills.

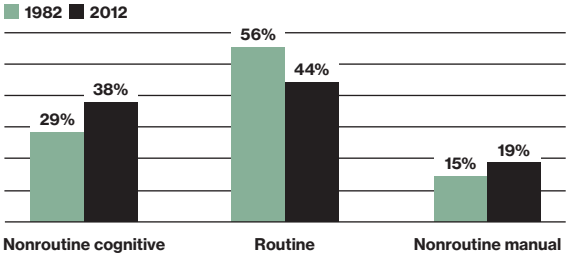
U.S. Median Real Earnings by Education Level, 1993–2013

Wages for men with a high school diploma have dropped as the number of production jobs has decreased and more men have taken low-paying jobs in food services, cleaning, and groundskeeping.



Share of U.S. Employment by Type of Occupation

Jobs are considered routine when they involve specific, repetitive tasks. These are the easiest jobs to automate.



Who's Working?

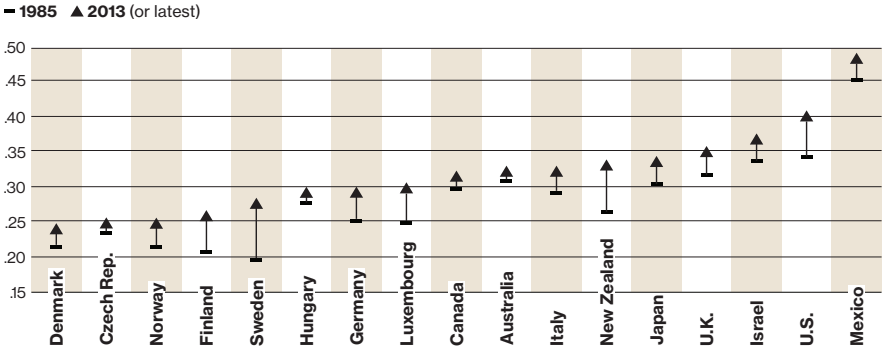
Fewer American men with high school diplomas or some college are employed full time.

1990 76%

2013 68%

Levels of Income Inequality in OECD Countries

Inequality as measured by the Gini coefficient, reflecting income distribution; 1.0 would be maximal inequality.



DATA FROM THE HAMILITON PROJECT; HENRY SIU, NIR JAIMOVICH; OECD

improved farming practices quickly transformed the United States from a country that needed many farmers to one that needed relatively few. It took the manufacturing boom fueled by World War II to finally help workers through the transition. Today, writes Stiglitz, we're caught in another painful transition, from a manufacturing economy to a service-based one.

Those who are inventing the technologies can play an important role in easing the effects. "Our way of thinking as engineers has always been about automation," says Hod Lipson, the AI researcher. "We wanted to get machines to do as much work as possible. We always wanted to increase productivity; to solve engineering problems in the factory and other job-related challenges is to make things more productive. It never occurred to us that isn't a good thing." Now, suggests Lipson, engineers need to rethink their objectives. "The solution is not to hold back on innovation, but we have a new problem to innovate around: how do you keep people engaged when AI can do most things better than most people? I don't know what the solution is, but it's a new kind of grand challenge for engineers."

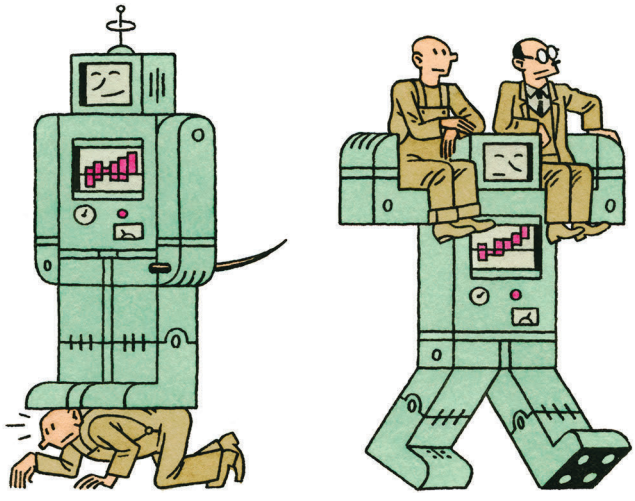
Ample opportunities to create jobs could come from much-needed investments in education, aging infrastructure, and research in areas such as biotechnology and energy. As Martin Ford rightly warns, we could be in for a "perfect storm" if climate change grows more severe at a time when technological unemployment imposes increased economic pressure. Whether this happens will depend in large part on which technologies we invent and choose to embrace. Some version of an automated vehicle seems inevitable, for example; do we use this to make our public transportation systems more safe, conve-

nient, and energy efficient, or do we simply fill the highways with driverless cars and trucks?

There is little doubt that at least in the short term, the best bulwark against sluggish job creation is economic growth, whether that's accomplished through innovative service-intensive businesses like the Apple stores and Uber or through investments in rebuilding our infrastructure and education systems. It is just possible that such growth will overcome the worries over robots taking our jobs.

Andrew McAfee, the coauthor with his MIT colleague Erik Brynjolfsson of *The Second Machine Age*, has been one of the most prominent figures describing the possibility of a "sci-fi economy" in which the proliferation of smart machines eliminates the need for many jobs. (See "Open Letter on the Digital Economy," page 11, in which McAfee, Brynjolfsson, and others propose a new approach to adapting to technological changes.) Such a transformation would bring immense social and economic benefits, he says, but it could also mean a "labor-light" economy. "It would be a really big deal, and it's not too soon to start the conversation about it," says McAfee. But it's also, he acknowledges, a prospect that is many decades away. Meanwhile, he advocates pro-growth policies "to prove me wrong." He says, "The genius of capitalism is that people find things to do. Let's give it the best chance to work."

Here's the rub. As McAfee and Brynjolfsson explain in *The Second Machine Age*, one of the troubling aspects of today's technological advances is that in financial terms, a few people have benefited from them disproportionately (see "Technology and Inequality," November/December 2014). As Silicon Valley has taught us, technology can be both a dynamic engine of economic growth and a perverse intensifier of income inequality.



In 1968, J.C.R. Licklider, one of the creators of today's technology age, co-wrote a remarkably prescient article called "The Computer as a Communication Device." He predicted "on line interactive communities" and explained their exciting possibilities. Licklider also issued a warning at the end of the paper:

"For the society, the impact will be good or bad, depending mainly on the question: Will 'to be on line' be a privilege or right? If only a favored segment of the population gets a chance to enjoy the advantage of 'intelligence amplification,' the network may exaggerate the discontinuity in the spectrum of intellectual opportunity."

Whoever owns the capital will benefit as robots and artificial intelligence inevitably replace many jobs.

Various policies can help redistribute wealth or, like the guaranteed basic income, provide a safety net for those at or near the bottom. But surely the best response to the economic threats posed by digital technologies is to give more people access to what Licklider called "intelligence amplification" so that they can benefit from the wealth new technology creates. That will mean providing fairer access to quality education and training programs for people throughout their careers.

It also means, says Richard Freeman, a leading labor economist at Harvard University, that far more people need to "own the robots." He's talking not only about machines in factories but about automation and digital technologies in general. Some mechanisms already exist in profit-sharing programs and employee stock-ownership plans. Other practical investment programs can be envisioned, he says.

Whoever owns the capital will benefit as robots and AI inevitably replace many jobs. If the rewards of new technologies go largely to the very richest, as has been the trend in recent decades, then dystopian visions could become reality. But the machines are tools, and if their ownership is more widely shared, the majority of people could use them to boost their productivity and increase both their earnings and their leisure. If that happens, an increasingly wealthy society could restore the middle-class dream that has long driven technological ambition and economic growth. ✠

David Rotman is the editor of MIT Technology Review.

Ann Marie Sastry, CEO of Sakti3

Survival in the Battery Business

The advanced battery market has seen many companies stumble in recent years. Startups with promising technologies for storing renewable energy or powering electric cars failed to find customers quickly enough (see "Why We Don't Have Battery Breakthroughs," March/April). But Sakti3, the maker of a novel solid-state battery, got a big boost this year when the British appliance giant Dyson said it would invest $15 million in the company and incorporate Sakti3's batteries into its products. Because it dispenses with the liquid electrolytes used in most batteries, which can cause chemical reactions that lead to overheating, a solid-state battery doesn't require bulky cooling systems and thus can deliver the same amount of energy in a much smaller package. Given that this could lead to electric cars with longer ranges than the ones available today, Sakti3—one of this year's 50 Smartest Companies—also counts General Motors as an investor. Founder Ann Marie Sastry spoke to *MIT Technology Review*'s senior editor for energy, Richard Martin.

Why would a vacuum cleaner company invest in a battery maker?
Because they need better batteries. What we're doing is building batteries in a very different way, such that we're able to generate very interesting properties. Our prototype systems today provide double the energy density of what's on the market. Even more important is that our technology offers a platform on which to continuously improve.

Why couldn't that happen with today's dominant battery technology?
The liquid-electrolyte systems that have been selected up to this point by manufacturers and the marketplace have been pursued for one principal reason: high energy density. But they have clear limitations in terms of weight, expense, safety, and so on. The continuous improvement in lithium batteries has enabled safe operations [of an electric car, for example] but at a high cost, and provided energy density that's appropriate for some ranges but is not equivalent to an internal-combustion engine. To continue to develop on that platform, as with any manufacturing process, is going to result in marginal gains at best.

At some point in any industrial process you have to ask, "Are we on the right platform?" We needed to eliminate the liquid-electrolyte system while still producing [at] a low cost and enabling out-of-the-gate safety. Our aim is no less than changing the way battery cells are made globally.

So what role might your batteries play in electric cars over the next, say, three years?
The automotive market is enormously important to us. We knew that we would probably have to commercialize first in markets with fewer barriers to entry, and with smaller [batteries]. Over the next three years, the work we are doing in the other markets will build our technology to address the rigorous demands of automotive markets—which is why we actually started the company in the first place.

Why solid-state as opposed to other battery chemistries?
The reason is that we see all the verticals for battery applications increasingly converging around the same needs: for portable systems with low environmental impact, high energy density, and safe, stable operations. Solid-state, if mastered, enables portability of even grid-scale systems, which we think will become increasingly important as renewables make greater incursions into grid power.

Portable systems for grid-scale power? That almost seems like an oxymoron.
I know! But think about Japan, for instance. People's houses in Japan are really small. If you tried to take a garage and fill it with batteries, that's not really practical. You need a storage system that can address different renewable sources, and the challenge is to produce a system that [can be] exactly optimized to the energy generation technology that is pertinent. Our thinking was that it should be small, agile, and customizable.

We're trying to follow what's been successful in technology advances in general: there are no mainframes anymore—everyone has agile, high-performance laptops. Energy storage shares many of the same principles.

How have you stayed afloat while other battery startups fell by the wayside?
We focused with great intensity on making the technology work on a low-cost platform. There are some businesses that pivot and change in response to market shifts, and that's very often a great strategy. We were extremely stubborn—which can also be useful at times.

LAURA MCDERMOTT

Biotech's Coming Cancer Cure

Supercharge your immune cells to defeat cancer? Juno Therapeutics believes its treatments can do exactly that.

By Antonio Regalado

Photographs by Lauren Lancaster

When Milton Wright III got his third cancer diagnosis, he cried until he laughed. He was 20 and had survived leukemia twice before, first when he was eight and again as a teen. Each time he'd suffered through years of punishing chemotherapy.

But now he had checked himself in to Seattle Children's Hospital. An aspiring model, he had taken a fall before a photo shoot and found he couldn't shake off the pain in his ribs. When the doctors started preparing him for a spinal tap, he knew the cancer was back. "I said, Oh, man, they are going to tell me I relapsed again," he recalls. "They're going to give me my six months."

The third time wasn't good, he knew. He'd seen enough sick kids at the Ronald McDonald House to know that when leukemia comes back like this, it's usually resistant to chemotherapy. Hardly anyone survives.

But Wright did. In 2013 his cancer, acute lymphoblastic leukemia, was destroyed with a new type of treatment in which cells from his immune system, called T cells, were removed from his blood, genetically engineered to target his cancer, and then dripped back into his veins. Although Wright was only the second person at Seattle Children's to receive the treatment, earlier results in Philadelphia and New York had been close to miraculous. In 90 percent of patients with acute lymphoblastic leukemia that has returned and resists regular drugs, the cancer goes away. The chance of achieving remission in these circumstances is usually less than 10 percent.

Workers process a patient's immune cells in a clean room at Memorial Sloan Kettering Cancer Center.

Those results explain why a company called Juno Therapeutics raised $304 million when it went public in December, 16 months after its founding. In a coup of good timing, the venture capitalists and advisors who established Juno by licensing experimental T-cell treatments in development at Seattle Children's, the Fred Hutchinson Cancer Research Center, and hospitals in New York and Memphis took the potential cancer cure public amid a historic bull market for biotech and for immunotherapy in particular. Its IPO was among the largest stock market offerings in the history of the biotechnology industry.

The T-cell therapies are the most radical of several new approaches that recruit the immune system to attack cancers. An old idea that once looked like a dead end, immunotherapy has roared back with stunning results in the last four years. Newly marketed drugs called checkpoint inhibitors are curing a small percentage of skin and lung cancers, once hopeless cases. More than 60,000 people have been treated with these drugs, which are sold by Merck and Bristol-Myers Squibb. The treatments work by removing molecular brakes that normally keep the body's T cells from seeing cancer as an enemy, and they have helped demonstrate that the immune system is capable of destroying cancer. Juno's technology for engineering the DNA of T cells to guide their activity is at an earlier, more experimental stage. At the time of its IPO, Juno offered data on just 61 patients with leukemia or lymphoma.

Juno is located in South Lake Union, a Seattle neighborhood dominated by Amazon.com, whose CEO, Jeff Bezos, was an early investor in the company. During a day spent at Juno's labs and offices in May, the phrase I heard repeated over and over was "proof of principle." That's what cases like Wright's have provided. The studies are small, with no control groups, no comparisons, but also no other explanation than T cells for why the cancer disappears. "It's proved that the T cell is the drug," says Hans Bishop, a former Bayer executive who is the company's CEO.

Bishop argues that medicine is entering a new phase in which cells will become living drugs. It is a third pillar of medicine. The pharmaceuticals that arose from synthetic chemistry made up the first pillar. Then, after Genentech produced insulin in a bacterium in 1978, came the revolution of protein drugs. Now companies like Juno are hoping to use our own cells as the treatment. In the case of T cells, the tantalizing evidence is that some cancers could be treated with few side effects other than a powerful fever.

Moving beyond the proof of principle won't be easy. No one has ever manufactured a cellular treatment of any commercial consequence. It's not certain what the best way to make and deliver such personalized treatments would be.

Nor is it clear whether engineered T cells can treat a wide variety of cancers; this year Juno and others are launching new studies to find out. Even in leukemia, cancer that affects the bone marrow and blood, it's too early to declare a cure. The majority of patients receiving the therapy have been treated only in the last 12 months. About 25 percent have seen their cancers roar back, sometimes mutated in a way that makes them immune to the T cells. At 18 months since his treatment, Wright, who hopes to become a police officer, is one of the longest survivors.

Juno isn't the only company chasing the T-cell idea. More than 30 companies have started clinical tests or are planning them, including Novartis, which says it may file for approval for a competing leukemia treatment in 2016. The U.S. Food and Drug Administration last summer gave both Novartis and Juno so-called breakthrough designation, meaning that their leukemia treatments could be approved after only one larger clinical trial.

If early results hold, tests of engineered T cells in blood cancers may lead to one of the fastest approvals in the history of drug development. It could take as little as seven years, whereas the average drug takes closer to 14 years. "That is unheard of in the industry," says Usman Azam, head of gene and cell therapy for Novartis.

At Juno I met the CFO, Steven Harr, who before joining the company was an investment banker specializing in biotech at Morgan Stanley. I asked whether he'd ever paid attention to cell therapy companies while on Wall Street. No, he said. Just the opposite. They were considered dogs, chasing an idea that didn't work—and even if it did, it was too complicated to commercialize. The FDA lists 14 approved cell therapies, most of which are skin grafts or involve storing umbilical cords.

But Harr says he "jumped on the bandwagon" when he saw the data from the leukemia patients. Now he thinks Juno will find an economic advantage by solving the difficult problem of how to commercialize cellular treatments. "It's a living thing—it's different from a pill," he says.

Medicine is entering a new phase in which cells will become living drugs.

Juno Therapeutics CEO Hans Bishop talks with staff in Seattle. The company had a huge IPO in December.

The treatment

"They hyped it up, like it was going to be amazing," Wright remembers. He'd signed up for the clinical trial right away, but he didn't tell anyone he was at the hospital. His mom was texting him: "Where you at? What's up?" After a few days he finally told her. "I'm at Children's. I'm getting ready for a trial." Wright underwent a two-hour process known as leukapheresis, in which his blood was passed through a device to separate out the T cells. The cells were taken to a lab, where a strand of new DNA was inserted using a virus. Two weeks later he got the treatment: a 10-minute drip from an IV bag to reinfuse the cells. Easy stuff compared with chemotherapy. And at first, nothing happened.

A sign of how potent the T-cell treatments are is that most patients suffer from "cytokine release syndrome," a storm of molecules generated as the cells fight the cancer. At least seven patients have been killed by the syndrome. Wright's doctors kept checking in to see if he had developed a fever, which would signal that the T cells were working. "They were pressuring me—'Come on, call us,'" he says. Two weeks later it came on like a body-flattening flu. He was admitted to the ICU and says he was barely lucid when smiling doctors told him they couldn't find cancer in his body.

Carl June, the University of Pennsylvania doctor who publicized some of the first successful treatments with engineered T cells, has likened what's happening inside patients' bodies to "serial killing" and "mass murder." As the billions of T cells in a dose multiply, they can locate and kill several pounds of tumor.

That's something normal T cells don't do. One reason is that they're trained not to harm your body, an effect known as tolerance. The training occurs in the thymus, the organ for which T cells are named. Each cell bristles with thousands of copies of a single receptor, its shape generated at random by shuffled DNA (a quintillion possible arrangements are possible). T cells whose receptor attaches strongly to surface markers, called antigens, on the body's own cells are discarded. The

1 A bioreactor bag holds a leukemia patient's T cells. The cells have been genetically modified to fight cancer. A new receptor has been added.

2 A bottle of nutrients is used to feed the T cells, which are grown for about 10 days, until they number in the billions. Then they can be reinfused into a patient's veins.

3 A sample of a patient's T cells is prepared for quality tests. This facility is located in Manhattan, at Memorial Sloan Kettering.

4 A worker mixes a vial of cells. The cost of preparing a dose of T cells can range from $50,000 to $75,000.

rest head out to patrol for foreign-looking viruses, bacteria, or infected cells, which they stick to and destroy. "The problem is that cancer *is* you," says Michel Sadelain, a researcher at Memorial Sloan Kettering Cancer Center and one of Juno's scientific founders. "The antigens on cancer just aren't that enormous and juicy."

Credit for the idea of getting around tolerance with an engineered T cell goes to an Israeli scientist named Zelig Eshhar. In a study published in 1989 in the *Proceedings of the National Academy of Sciences*, he replaced the T cell's natural receptor with one that he chose. Eshhar realized that with his technique, a T cell could be engineered to attach to whatever it was instructed to attach to.

It's an idea as dangerous as it is powerful. The reason is that few antigens appear exclusively in cancer cells. In 2009, a woman given T cells engineered to recognize colon cancer suddenly went into respiratory distress; she died five days later. Doctors at the National Cancer Institute quickly canceled the study, concluding that the T cells had encountered their antigen in her lungs and attacked.

Scientists like Sadelain soon zeroed in on one ideal antigen, called CD19. It appears nowhere in the body except on B cells, the same kind that go awry in lymphoma and in the leukemia that afflicted Wright. And it turns out that wiping out a person's B cells isn't life-threatening. With shots of immunoglobulin, you can live without any for years.

By 2010, doctors at Memorial Sloan Kettering, Penn, and the National Cancer Institute had begun trying to treat leukemia patients with T cells bearing a doctored receptor for CD19. To the inside of the receptor, they'd added another snippet of DNA that stimulates the cells to divide. No one is sure how the stimulation works, but without it, the modified T cells don't do much. Early case reports eventually multiplied into trials that have treated about 350 leukemia and lymphoma patients. The results are remarkable, partly because they're so consistent, even though each lab uses slightly different DNA designs.

Fast follower

Penn's first results were well publicized and drew the attention of Novartis, the world's second-largest drug company. In August 2012, it agreed to give the university $20 million to build a new cell-therapy center as part of an alliance through which Penn's T-cell therapies will be sponsored and owned by the Swiss pharmaceutical giant. The deal was notable for being struck on the basis of published data from just three patients, and now it looks like a bargain.

It also makes Juno a "fast follower," in startup parlance. Incorporated in August 2013, it is "a company of many fathers," says Lawrence Corey, an infectious-disease doctor who was then the president of Fred Hutchinson. Corey, aided by the venture capitalist Bob Nelsen and Richard Klausner, the former director of the National Cancer Institute and now chief medical officer of the DNA-sequencing company Illumina, created Juno by buying up patents and licensing rights to T-cell trials under way in Seattle and at Sloan Kettering in New York.

Since its IPO, Juno's stock market value has surged above $6 billion, reflecting intense speculation that engineered T cells will prove to be a new way to treat many types of cancer,

It's an idea as dangerous as it is powerful. At least seven patients have been killed.

not only the relatively rare leukemia Wright suffered from. Juno's executives believe that they can quickly come up with new T cell designs and obtain a "fast readout" by testing them in terminal cancer patients, where risks are easy to justify. The company plans to have 10 studies of six different T-cell designs in progress by next year. "We are looking for breakthroughs," says Mark Frohlich, a doctor who is Juno's vice president for strategy. "We aren't going to say, 'Okay, two months survival.'"

The big question mark is whether T cells will work in cancers other than those of the blood. The week before I visited Juno, investors briefly sent its shares tumbling by 35 percent after Novartis and Penn reported that low doses of engineered T cells had no dramatic effects in five patients with cancers of the pancreas, ovaries, or lung. Still, the data were too preliminary to indicate much. "We know it's feasible. But how many cancers can you apply this to? That we don't know," says Sadelain. "What's changed is that everyone now knows what to do. I think that partly explains the frenzy around T cells."

The goal is to find the next CD19. But that's not easily done. Since few antigens appear only on tumor cells, any targeted T cell runs the risk of wiping out vital organs, as happened to the colon cancer patient in 2009. The Recombinant DNA Advisory Committee, a federal body that oversees gene therapy, called a meeting this June to debate how scientists planned to avoid these and other side effects. One way to lessen the risk is already being tested in patients: "suicide switches," which

Michel Sadelain, shown here at Memorial Sloan Kettering, helped carry out one of the first clinical trials of T cells in leukemia patients.

let doctors rapidly kill off all the engineered T cells should any serious problems arise. This spring, Michael Jensen, a pediatric cancer doctor at Seattle Children's whose cell-therapy center treated Wright, opened a study to treat neuroblastoma, the most common cancer affecting infants. He says T cells will target an antigen found on nerve cells. If the T cells do unexpected damage, they can be inactivated with a dose of the drug Erbitux.

Safety isn't the only obstacle. How can engineered T cells be made to persist in a person's body to provide permanent protection? So far they don't seem to linger in many patients, something Frohlich terms a "big problem." And dense organ tumors can saturate their surroundings with signals, like a molecule called PD-L1, that turn T cells off. This defense is the process that checkpoint inhibitors, the new immunotherapy drugs sold by Merck and Bristol-Myers Squibb, interfere with. But DNA engineering may offer clever solutions as well. Jensen says he rewired the DNA of T cells so this "off" signal instead provokes them to kill even more.

Jensen is optimistic that rapidly improving techniques for modifying genes, and for handling and growing cells, will let researchers conquer solid tumors. "What is in the clinic now with leukemia is version 1.1 of this operating system," he says. "But back in the labs, that is already antiquated technology."

Given that it took 20 years to come up with the results in leukemia, Sadelain told me, "it would be naïve to expect a breakthrough every quarter." Yet a dozen newly launched studies on T cells mean some big results could be in the wings.

One study I heard about is led by Marcela Maus, an oncologist at Penn, who this year tested engineered T cells in five patients with glioblastoma, an incurable brain cancer. When one of these patients underwent brain surgery, Maus discovered that the tumor had been mostly killed. No cancer cells with the marker she'd aimed at remained at all. So was this proof that T cells can treat brain cancer, too? Maus is reluctant to answer that question. "Potentially," she says. It's just too soon to know if these patients will live any longer than they would have otherwise. "It's hard to exercise patience, but that is what is needed," she says.

Commercial barriers

When Wright's white blood cells were collected in late 2013, they headed to a processing facility at Seattle Children's. Workers laboring in masks and safety suits placed them into bioreactors and used a virus to insert the new DNA. Then the cells were grown for 10 days inside plastic sacks fed with human blood serum. If a half-dozen academic centers hadn't built specialized clean rooms like this one, there wouldn't be any clinical trials, or any IPOs. But Jensen's center is no commercial operation: it can prepare cells for only 10 patients a month. It costs $75,000 to manufacture cells for each one.

Jensen says about a quarter of the children whose parents want to enter them in the Seattle study aren't accepted. Some-

"There's no model for how much it costs. But remember, we get to utter words like 'cure.'"

times the reasons are medical, but not always: capacity is simply limited. "I wish every kid could get it," Jensen says of the cell treatment. "The major barrier is the commercial end of it—having their factories built, having their trials done, and it being something that a doctor would be able to write a prescription for in any part of country."

In fact, no one is quite sure how a personalized cell therapy will be commercialized at a large scale. Schematics outlining how it would work typically show not just a dozen complex laboratory steps but two airplanes, to get cells to and from patients. That explains why the largest number of Juno's employees are involved in process engineering. One of them, Chris Ramsborg, gave me a tour around what he called the "sandbox" where new ideas for growing and packaging cells are being worked out. But most of the equipment was hidden from sight. "The manufacturing technology and how we are deploying it is the secret of Juno," he said. "The techniques to make these products don't really exist yet."

Cancer doctor Michael Jensen heads an immunotherapy program at Seattle Children's Hospital.

Several members of Juno's staff, including Ramsborg, Frohlich, and Hans Bishop, worked at another Seattle biotech named Dendreon, which developed a T-cell treatment for prostate cancer. (The cells, instead of being engineered, were exposed to cancer antigens and then multiplied. The treatment was only modestly effective.) Even though Dendreon charged $93,000 for its treatment, it cost half that much to manufacture. The company filed for bankruptcy last year.

Dendreon's manufacturing plant in New Jersey was scooped up by Novartis, which has started using it to process cells for patients involved in its leukemia study. Azam says Novartis, which has 400 people working in gene and cell therapy, is already studying the logistics of how a personalized cell therapy could be offered globally. "We have been mapping out how we would do the patient journey, the individual cell journey," he says. "It's a new way to treat patients, but also a new way of practicing business."

It may one day be possible to mass-produce off-the-shelf T cells or even do genetic engineering at a patient's bedside. Some labs are working with instruments to pump genetic material into cells using electricity or pressure. Others have shown they can generate T cells in a lab dish and use them to cure mice, raising the possibility of T-cell factories. For now, though, all the engineered T-cell treatments in clinical testing use a patient's own cells.

So how much will a dose of genetically engineered immune cells cost? One Citigroup analyst estimated that the price could exceed $500,000. That would be more expensive than nearly any existing cancer drug. Yet it might be considered cheap if a 10-minute drip could effectively treat leukemia without causing permanent damage to the patient. Current chemotherapy treatments last for a year or more and can weaken a person's heart and body for a lifetime. The hospital bills for leukemia patients can top $2 million.

Harr, Juno's CFO, was well known on Wall Street for criticizing the high cost of cancer drugs; he warned that the government might step in and set prices if they weren't reined in. When I asked him about the T-cell treatments, he said it was too soon to guess at a price. It depends how well they work and how hard they are to make. "There's no model for how much it costs," he said. "But remember, we get to utter words like 'cure.' And at this point, it's a single dose."

Antonio Regalado is MIT Technology Review*'s senior editor for biomedicine.*

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Sometimes we hear that technology companies have lost their ambition. Too many great minds are pouring their energy into the next app for the affluent, the argument goes. Where is the daring?

Right here. This year, when the editors of *MIT Technology Review* began our annual search for the smartest companies, we did not have trouble finding big ideas. To make the list, a company must have truly innovative technology and a business model that is both practical and ambitious, with the result that it has set the agenda in its field over the past 12 months.

No. 1, Tesla Motors, has added another audacious idea to go with its electric cars. In April, it announced it would be spinning off a line of batteries in service of a big goal: remaking the energy grid for industry, utilities, and residences.

Of all the sectors we cover, biomedicine has had the biggest year. Companies have turned research breakthroughs, many powered by genomic analysis, into products that treat challenging diseases. Gilead Sciences, No. 15, sells the first pill that can cure most cases of hepatitis C. Bristol-Myers Squibb, No. 26, is selling an immunotherapy drug that is saving the lives of people with skin and lung cancer.

By contrast, energy companies have been far less innovative, it seems to us, so that sector plays a smaller role on this list. One highlight is No. 6, SunEdison, which is electrifying developing countries.

As always, many newer, private companies can be found here, starting with No. 5, Counsyl, a startup whose cheap, automated DNA analysis is expanding from prenatal testing to cancer screening.

A few giants return after an absence from the list: Microsoft, at No. 48 for its wearable HoloLens device that blends virtual reality and the real world, and Apple, No. 16, for its well-designed smart watch and digital-wallet service. All share one feature: they are innovations with impact. *—Nanette Byrnes*

Illustration by Seymour Chwast

50 Smartest Companies 2015

1. TESLA MOTORS
Extending its battery technology from cars to residential and commercial applications.

***$5 billion**: projected investment required to build its battery "gigafactory" in Nevada*

2. XIAOMI
Fast-growing smartphone vendor is maturing beyond its original "cut-price Apple" model with ideas like flash sales over its mobile messaging platform.

***$45 billion**: most recent valuation for the private company*

3. ILLUMINA
Shifting its fast DNA-reading machines from research applications primarily to hospitals and cancer clinics.

***90 percent**: proportion of all DNA data estimated to be produced on its machines*

4. ALIBABA
The world's largest online retailer, it conducts more than half its daily transactions through its Alipay digital wallet/banking service.

***$25 billion**: amount raised in its record-setting IPO*

5. COUNSYL
Its cheap DNA tests help would-be parents plan ahead. Now it sells cancer screens.

***3.6 percent**: proportion of U.S. couples that use its tests before trying to conceive*

6. SUNEDISON
Aggressively expanding its renewable energy products and building a business to provide electricity to the developing world.

***1.1 billion**: number of people worldwide who don't have access to electricity*

7. TENCENT
China's most-used Internet service portal is expanding by investing in companies inside and outside its home market.

***549 million**: active monthly users on WeChat and its related Weixin service*

8. JUNO THERAPEUTICS
Testing cancer treatments that use a person's own immune cells.

***$265 million**: amount it raised in the largest biotech IPO of 2014*

9. SOLARCITY
The factory it is planning to build in Buffalo will be the Western Hemisphere's largest manufacturer of silicon solar panels, the company says.

***177,000**: number of U.S. customers who lease SolarCity's rooftop solar panels*

10. NETFLIX
It's producing innovative original content and inking distribution deals with cable companies.

***31**: number of Emmy nominations for its original programming in 2014*

(p.60)

11. OVASCIENCE
The first baby conceived with the help of its stem-cell treatment has been born.

***$25,000**: maximum amount it charges IVF clinics for the treatment*

12. GOOGLE
Its Loon balloons are designed to broaden Internet access.

***30**: number of balloons launched from New Zealand's South Island in Google's 2013 pilot test*

13. AMAZON
Robots now used in its fulfillment centers could make the facilities far more efficient.

***$89 billion**: 2014 sales*

14. ALIVECOR
Maker of a heart monitor that connects to an iPhone and automatically detects irregular heartbeats.

***2 million**: number of ECG readings on its devices so far*

15. GILEAD SCIENCES
Began selling the first pill that can cure most cases of hepatitis C.

***$3.6 billion**: sales of the drug in the first three months of 2015*

16. APPLE
Its new smart watch and its Apple Pay digital wallet set the pace for competitors.

***1 million**: number of Apple Watches ordered the day they went on sale, according to outside estimates*

17. VOXEL8
Having created what it calls the world's first 3-D electronics printer, the startup is commercializing promising new materials like conductive ink.

***5,000**: factor by which its inks improve conductivity, according to the company*

18. IDE TECHNOLOGIES
Offering more affordable water desalination at a scale never before achieved.

***300,000**: number of people to be served by the plant it is building with partners in Carlsbad, California*

19. AMGEN
Its Icelandic gene database is yielding clues that help it decide which drugs to develop.

***10,000**: number of sequenced genomes in the database*

20. AQUION ENERGY
Has gained customers for its novel batteries, which can store surplus wind and solar energy.

***$129 million**: money raised from Aquion's investors*

21. BAIDU
The Chinese Internet company's new deep-learning research lab has produced notable results in facial and speech recognition.

***70 percent**: increase in 2014 research spending, to $1.125 billion*

22. SPACEX
The rocket company has made progress on the technical challenge of landing and reusing unmanned rockets.

***9**: number of missions completed in the last year*

(p.34)

23. SAKTI3
Uses new materials and manufacturing techniques to make solid-state batteries that store twice as much energy as rival lithium-ion technologies.

***$15 million**: size of recent investment by appliance maker Dyson (General Motors is also a backer)*

24. FREESCALE SEMICONDUCTOR
Pioneering technology to be used in advanced computer vision systems for cars.

***$12 billion**: Freescale's value in a proposed acquisition by a Dutch semiconductor maker*

25. UNIVERSAL ROBOTS
Its user-friendly, relatively cheap robots have found a strong market. In May, Teradyne agreed to buy the company for $285 million.

***70 percent**: increase in revenue from 2013 to 2014*

26. BRISTOL-MYERS SQUIBB
Took a lead in cancer immunotherapy with Opdivo, a life-saving drug for skin and lung cancer.

***$12,500**: monthly cost of the drug*

27. TELADOC
Though some doctors' organizations oppose the idea of remote medicine and are trying to limit the practice, this fast-growing telemedicine company is nearing an IPO.

***10 million**: number of U.S. members in its remote-consultation service*

28. NVIDIA
Its chips are crucial for cutting-edge technologies like deep learning and driverless cars.

***7,000**: number of patents it holds*

29. FACEBOOK
Big ad revenue is being invested in improvements to apps like Messenger and in its new agreement to directly host work by leading news organizations.

***1.44 billion**: number of monthly active users worldwide in the first quarter of 2015*

30. ALNYLAM
It is turning around the prospects for RNA interference, a promising type of gene therapy that has been challenging to use.

***6**: number of the company's drugs in human testing*

31. RETHINK ROBOTICS
Although sales have been soft for its easy-to-train Baxter robot, the company's newest model, Sawyer, is impressively precise and fast.

***$114 million**: funding raised*

32. PHILIPS
The giant of LED lighting has made the efficient technology even more affordable.

***$5**: retail price of two bulbs that will last for a decade*

33. CELLECTIS
Its Calyxt division uses quick gene editing to create crops that might not need regulation as GMOs.

***1 year**: time it took to create a genetically engineered potato that should be healthier to eat when fried*

34. BLUEBIRD BIO
Its gene therapies may cure, not just treat, diseases like sickle-cell anemia.

***9**: number of patients treated so far in studies*

35. THYSSENKRUPP
Reinvented the elevator with magnetic levitation technology, resulting in a system that can transport more people and move horizontally.

***6.4 billion euros**: company's global elevator sales in 2014*

(p.52)

36. SLACK
Its workplace communications app is taking off.

***300 million**: number of messages sent via Slack each month*

37. LINE
The Japanese company runs a hugely popular messaging and free calling app that actually generates revenue.

***181 million**: number of monthly active users*

38. IMPROBABLE
Using computer science to simulate richer virtual worlds, with applications in gaming and virtual reality.

***$20 million**: Improbable's funding from Andreessen Horowitz this year*

39. ENLITIC
Its deep-learning technology automatically spots tumors in medical scans.

***$1.7 billion**: total estimated value of the market for medical image analysis software*

40. COINBASE
Helps companies including PayPal, Dell, and Expedia take Bitcoin payments without having to hold onto the cryptocurrency.

***2.9 million**: number of Bitcoin accounts registered with Coinbase*

41. HACON
Its popular travel planning apps in Europe combine information on taxis, car rental, bike sharing, and public transportation systems.

***40 million**: number of journeys planned on its system every day*

42. 3D SYSTEMS
Moving to dominate the commercialization of 3-D printing by developing a super-fast assembly line.

***50**: factor by which 3D Systems hopes to increase the speed of 3-D printing*

43. GENERALI
This Italian-based insurer will use fitness data from wearables, as well as other health data, to calculate insurance rates for customers who choose to participate.

***60**: number of countries in which the company operates*

44. INTREXON
Developing synthetic biology in multiple fields for health, energy, consumer, and environmental applications.

***$41 million**: amount paid to acquire the maker of a patented transgenic apple*

45. DNANEXUS
Helping researchers and drug companies move genetic data into Amazon's cloud.

***56,000**: number of computer processors the company uses to analyze DNA*

46. IBM
Novel research into artificial intelligence could help the company in its long-term plan to make big data more useful.

***14**: number of hospitals in North America that have signed up to use the Watson AI system to guide cancer therapy*

47. SNAPCHAT
Innovative new formats include "Snapchat Stories," which put videos and photos together to tell a story, and a platform for media organizations that is used by ESPN, CNN, and others.

***1 billion**: number of Snapchat Stories viewed per day*

48. MICROSOFT
Its HoloLens augmented-reality technology reflects the new CEO's turnaround ambitions.

***13 percent**: increase in revenue so far this year*

49. IMPRINT ENERGY
Developing ultrathin, flexible, rechargeable batteries that can be printed cheaply on commonly used industrial screen printers.

***350 micrometers**: width of batteries capable of powering an ultrathin Bluetooth wireless sensor or a wearable device*

50. UBER
It's testing ideas like ride-share services and driver deliveries.

***162,037**: number of active Uber drivers as of December 2014*

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the global population will reach 9.6 billion. How will we live together productively and in good health, when the planet is already stressed today?

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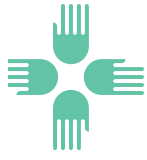

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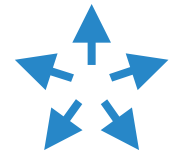

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Cyber-Espionage Nightmare

A groundbreaking online-spying case unearths details that companies wish you didn't know about how vital information slips away from them.

By David Talbot

ALEX WILLIAMSON

Prosecutors say they traced computer break-ins to these agents in Shanghai, who allegedly used such online nicknames as UglyGorilla.

On a wall facing dozens of cubicles at the FBI office in Pittsburgh, five guys from Shanghai stare from "Wanted" posters. Wang Dong, Sun Kailiang, Wen Xinyu, Huang Zhenyu, and Gu Chunhui are, according to a federal indictment unsealed last year, agents of China's People's Liberation Army Unit 61398, who hacked into networks at American companies—U.S. Steel, Alcoa, Allegheny Technologies (ATI), Westinghouse—plus the biggest industrial labor union in North America, United Steelworkers, and the U.S. subsidiary of SolarWorld, a German solar-panel maker. Over several years, prosecutors say, the agents stole thousands of e-mails about business strategy, documents about unfair-trade cases some of the U.S. companies had filed against China, and even piping designs for nuclear power plants—all allegedly to benefit Chinese companies.

It is the first case the United States has brought against the perpetrators of alleged state-sponsored cyber-espionage, and it has revealed computer-security holes that companies rarely acknowledge in public. Although the attackers apparently routed their activities through innocent people's computers and made other efforts to mask themselves, prosecutors traced the intrusions to a 12-story building in Shanghai and

outed individual intelligence agents. There is little chance that arrests will be made, since the United States has no extradition agreements with China, but the U.S. government apparently hopes that naming actual agents—and demonstrating that tracing attacks is possible—will embarrass China and put other nations on notice, inhibiting future economic espionage.

That may be unrealistic. Security companies say such activity is continuing, and China calls the accusations "purely ungrounded and absurd." But there's another lesson from the indictment: businesses are now unlikely to keep valuable information secure online. Whatever steps they are taking are not keeping pace with the threats. "Clearly the situation has gotten worse, not better," says Virgil Gligor, who co-directs Carnegie Mellon University's computer security research center, known as CyLab. "We made access to services and databases and connectivity so convenient that it is also convenient for our adversaries." Once companies accept that, Gligor says, the most obvious response is a drastic one: unplug.

Fracking and hacking

Sitting at a small conference table in his office in the federal courthouse in Pittsburgh, David Hickton, the United States attorney for western Pennsylvania, opened a plastic container he'd brought from home and removed and peeled a hard-boiled egg for lunch. Although we were discussing an investigation involving global players and opaque technologies, the homey feel of our meeting was apt: the case had many roots in close-knit business and political circles in Pittsburgh. Hickton showed me a framed photo on a shelf. In the picture, he and a friend named John Surma are standing next to their sons, the boys wearing hockey uniforms, fresh from the ice. Both fathers had attended Penn State. As Hickton rose in the prosecutorial ranks, Surma rose in the corporate world, becoming CEO of U.S. Steel. When Hickton became the top federal prosecutor in the area in 2010, one of his meet-and-greet breakfasts was with Surma and Leo Girard, the boss of United Steelworkers, which represents 1.2 million current or retired workers in several industries. "I was asking them in a completely unrelated matter to serve on a youth crime prevention council," Hickton recalls. "They said, 'Can we talk to you about something else?'"

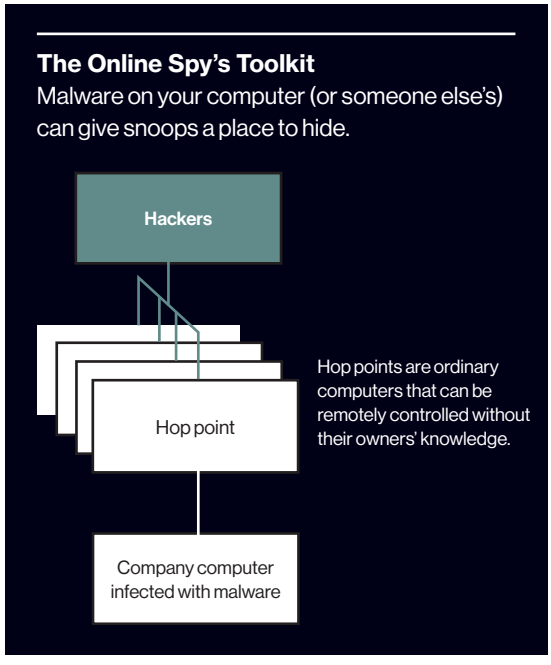
At the time, the American fracking boom was in full swing, with ultra-low interest rates that had been set to stimulate the economy also lubricating the business of extracting previously hard-to-reach natural gas and oil. U.S. Steel had a flourishing business selling pipes specially designed for the extraction process. Among other traits, the pipes have no vertical seams, so they will hold up as they're rammed thousands of feet into the earth and yet bend to convey oil and gas without breaking.

But U.S. Steel also noticed two unsettling developments. First, Chinese state-owned companies were exporting lots of similar pipe into the United States at low prices. So U.S. Steel filed complaints with the U.S. Department of Commerce and the U.S. International Trade Commission, accusing China of subsidizing its industries; the resulting cases ultimately led to sanctions against China. Second, both the company and the union were aware that suspicious e-mails had come in. But it wasn't clear who was behind them or whether any damage was occurring. "There was a general awareness of intrusions, but not 'when, where, how' and the scope," Hickton says.

The e-mails were cleverly designed. They purported to be from colleagues or board members, with subject lines relating to meeting agendas or market research, but they delivered malware by means of attachments or links. For example, the indictment says, on February 8, 2010—two weeks before a preliminary ruling from the Commerce Department—the hackers sent an e-mail to several U.S. Steel employees. It seemed to be from the CEO but included a link to a website that held malware. A few employees clicked it, and their computers were soon infected. The result: the hackers stole host names for 1,700 servers that controlled access to the company's facilities and networks. The indictment says Wang then tried to exploit that access, but it doesn't specify what information was exposed.

Debbie Shon, U.S. Steel's vice president for trade, told me that the information included valuable business intelligence. "It wasn't high-tech designs," she says. "It was the equally important stuff—the business strategies, the pricing, the production amounts, and the timing and content of any trade complaints that U.S. Steel, as one of the biggest companies in this area, might be exploring."

The indictment details several similar attacks. Between 2007 and 2013, Westinghouse was negotiating the details of a contract with a Chinese company to build four nuclear reactors. From 2010 to 2012, one of the defendants allegedly stole at least 1.4 gigabytes of data—roughly 700,000 pages of e-mail and attachments—from Westinghouse's computers. The files included piping designs and communications in which Westinghouse disclosed worries about Chinese competition. At ATI, the hackers allegedly stole the passwords of 7,000 employees while the company was in a trade dispute focused on its sales to China. At Alcoa, prosecutors allege, the hackers stole 2,900 e-mails with more than 860 attachments around the time the company was negotiating deals with Chinese businesses. (Alcoa, Westinghouse, and ATI all declined to comment for this story.) And in 2012, after the steelworkers' union started speaking out against Chinese industrial policies, Wen stole e-mails containing discussions among union leaders, the indictment says.



Meanwhile, SolarWorld had brought trade cases accusing Chinese companies of selling solar panels below cost, decimating their rivals. One day in 2012, a phone rang at its offices in Camarillo, California. It was the FBI calling, saying that agents had discovered e-mails stolen from the company, says Ben Santarris, its U.S. spokesman. In a sign of just how bad cybersecurity is, "there was no inkling this was going on until we got the phone call," he says. Only when the indictment was unsealed in May 2014 did the company learn the full scope of the alleged theft. "There was access to trade-case strategy, company financials, costs, profit-and-loss statements, technology road maps, R&D, and so on," Santarris says. Ultimately the company won its cases, securing duties on imports of solar equipment from China. During the trade dispute, "we were observing very tight controls over who gets to see what information," he says. "At the time we were doing that, according to the FBI, the Chinese military was coming in the back door."

Take it down

The failure of the companies' supposed security technologies was stupefying. Lance Wyatt, the IT director for the steelworkers' union, thought he ran a tight ship. An IT audit in 2010 had found no major deficiencies. His e-mail server screened all incoming messages for attachments that contained executable code. He had the latest antivirus software. His network checked IP addresses to avoid sites that contained malware. Yet Wyatt and the FBI eventually found infected computers, one of them used by the union's travel manager. "None of those machines were on our radar as being infected or suspect," he says.

According to the indictment, the hackers had various means of disguise. For one thing, they allegedly sent malicious e-mail into companies and the union from hop points—intermediate computers, including one in Kansas, that were under their control. Second, they skillfully manipulated the Internet's system for naming computer addresses. The hackers set up domain names such as "arrowservice.net" and "purple-daily.com" and programmed malware on the corporate victim computers to contact them. Then the spies could continually change the computer addresses to which the domain names connected. When it was daytime in Shanghai and nighttime in Pittsburgh, the indictment says, they'd set a domain name to connect to hop-point computers and conduct espionage. When the Shanghai workday was done, the hackers would set the address to connect to innocuous sites such as Yahoo pages.

It's not a surprise that such systems are relatively easy to co-opt for nefarious purposes. Ideas for making the Internet more secure have been around for decades, and academic and government labs have churned out interesting proposals. Yet very few of these ideas have been implemented; they require broad-based adoption and possibly trade-offs in network performance. "You don't hear about rebuilding the Internet anymore," says Greg Shannon, chief scientist at the CERT division of Carnegie Mellon's Software Engineering Institute.

What's a company to do? Wyatt tightened things at United Steelworkers; among other things, he now gives fewer employees so-called administrative privileges to their computers, and he searches the network for the telltale signs of communications by malware. But none of this would have prevented the intrusions. Wyatt says it "might have slowed them down."

The best option, then, could be to get sensitive data off the Internet entirely. There are downsides to that: if e-mail is not used as freely, or a database is offline, keeping up with the latest versions of reports or other data could be more time-consuming. But as Gligor says: "We must pay the cost of security, which is inconvenience. We need to add a little inconvenience for us to make things much harder for the remote attacker. The way to do that is to—how should I put it?—occasionally go offline."

After all, more attacks like the ones in Pittsburgh are still occurring. "This indictment," Hickton says, "does not represent the full number of hackers, full number of victims, or full number of defendants."

David Talbot is MIT Technology Review*'s senior writer.*

Stewart Butterfield, CEO of Slack

The New Water Cooler

You probably haven't heard of an online game called Glitch. It existed for only a little while before the company that built it, Tiny Speck, closed it down in 2013. And yet we have Glitch to thank for a tool that is changing how people in many organizations get their work done.

When they were developing Glitch, Tiny Speck's employees were scattered between San Francisco, New York, and Vancouver. To make it easier to communicate, the team created an instant-messaging program that could serve as a hub for everything they were doing. It archived messages, just as you'd expect in e-mail, but it also made it possible to see and search information from other sources, such as their daily status reports and file servers. Soon they realized that this application, now known as Slack, was potentially useful to any organization and could be a far bigger opportunity than Glitch. After some of the fastest growth ever seen in business software, today Slack has 750,000 users, and the company that has come together to develop it is valued at nearly $3 billion. It's a member of this year's 50 Smartest Companies list.

Slack is headed by Stewart Butterfield, who cofounded the photo-sharing site Flickr and sold it to Yahoo in 2005 for more than $20 million. He told *MIT Technology Review*'s senior editor for mobile, Rachel Metz, that he hopes Slack will do for all companies what it did for his: free people up to get more work done.

There are many communication apps for work that offer aspects of what people can do with Slack. How is Slack different?

Usually within a single organization there will be many, many different means of communication. There's this huge value in bringing all those together. So if you can provide a tool that works for both ends of the spectrum—like "I'm going to be five minutes late to the meeting" but also "Here's an important change to our benefits policy that all employees must be made aware of, and you have until June 30 to file some form," or something like that—if it works for all of those and all the use cases in between those, then it will either consolidate or replace many other forms of communication. The fact that there's only one place, one tool that you have to check, one record of all the conversations, and the fact that it's searchable, makes a huge difference.

I've heard of not just companies using Slack but classroom teachers as well.

We hear of people using it with their family. I have heard of a couple using it.

Despite its popularity, you've told me in the past, perhaps somewhat tongue in cheek, that Slack is "just a giant piece of shit." Is it still?

I think we've made some improvements since then, but on the whole there are still so many problems. There are a lot of things that are still shockingly bad. Amazingly, you actually cannot invite people from the mobile app if you've just created a team. It's just not possible. And that's insane. It's inconvenient for people, obviously, and frustrating because people just assume, "I have this brand-new messaging app on my phone—how do I invite people?" And they'll try every single thing through the whole app. It's also incredibly stupid for us as a business, right?

Assuming you can fix that, what's a feature you'd want to add that is impractical or technologically impossible for now?

Automatic summarization of what happened while you were away. It sounds very simple in one sense. But doing it right will be very difficult. If I said to Bob or Amy, "Go read all of the messages that came in over the course of the day that I haven't looked at yet and tell me the three most important things that I need to deal with right away," it would be very easy for them to do that, whereas asking a computer to do that is impossible. So that's something we're very interested in—especially not just the ability to do it in a one-off way but also, ideally, the ability to learn from me about what I think is important and the way in which I would like it presented.

Slack has a free service, but you charge for some features. How big a business can this become?

What we're doing now is an amazing business. In [software as a service] businesses, the benchmark for churn [loss of customers] is typically 1 percent a month—that's kind of the boundary between good and maybe starting to be dangerous. Anything over 1 percent starts to be worrying. We're not even at a tenth of a percent per month. Essentially, no one ever stops paying us once they start paying us.

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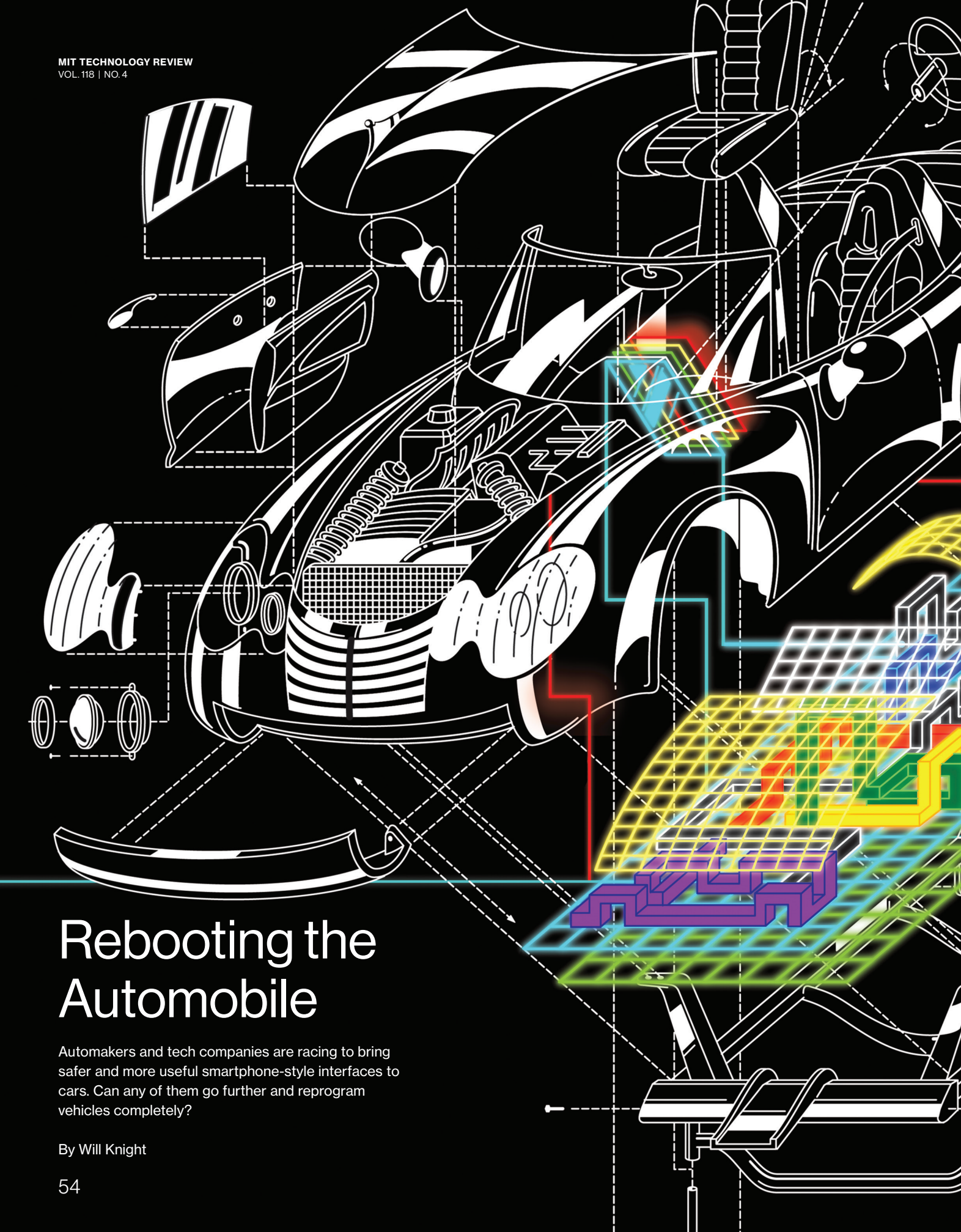
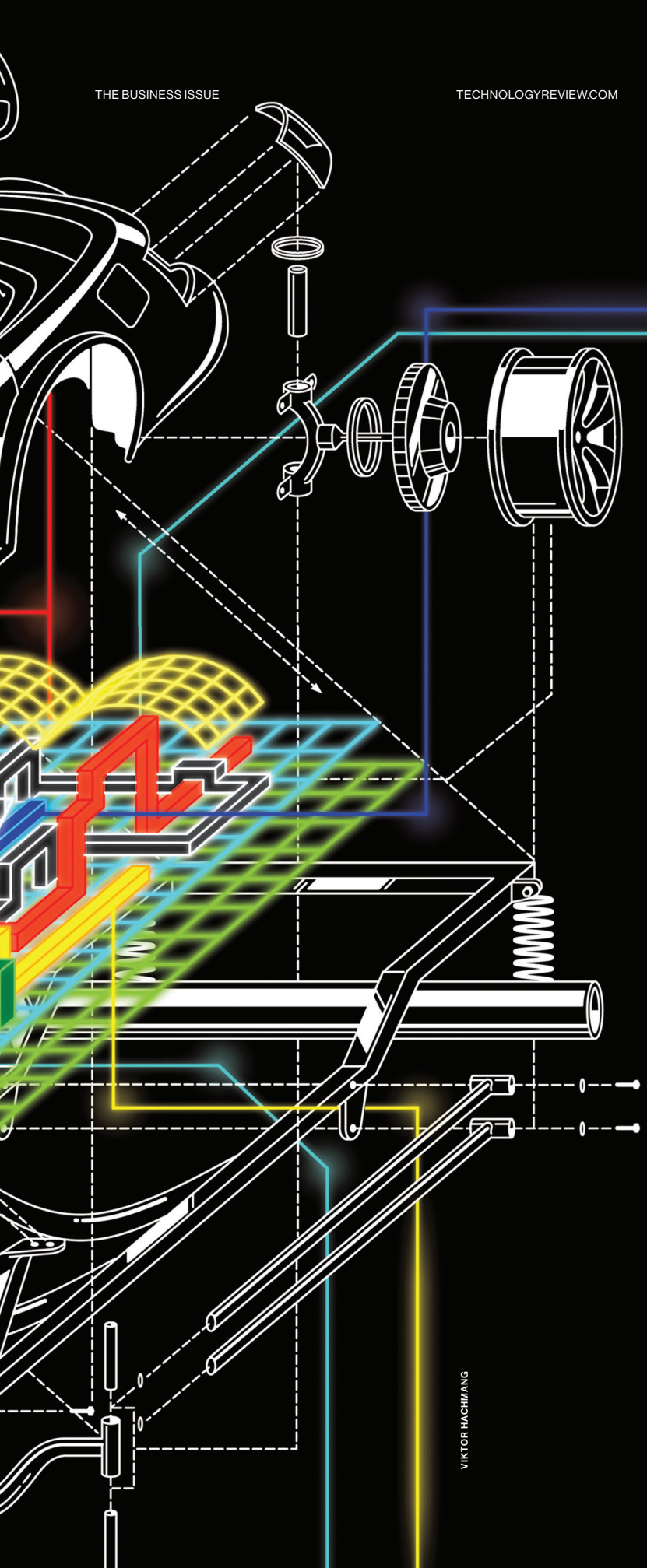


Rebooting the Automobile

Automakers and tech companies are racing to bring safer and more useful smartphone-style interfaces to cars. Can any of them go further and reprogram vehicles completely?

By Will Knight



VIKTOR HACHMANG

"Where would you like to go?" Siri asked.

It was a sunny, slightly dreamy morning in the heart of Silicon Valley, and I was sitting in the passenger seat of what seemed like a perfectly ordinary new car. There was something strangely Apple-like about it, though. There was no mistaking the apps arranged across the console screen, nor the deadpan voice of Apple's virtual assistant, who, as backseat drivers go, was pretty helpful. Summoned via a button on the steering wheel and asked to find sushi nearby, Siri read off the names of a few restaurants in the area, waited for me to pick one, and then showed the way on a map that appeared on the screen.

The vehicle was, in fact, a Hyundai Sonata. The Apple-like interface was coming from an iPhone connected by a cable. Most carmakers have agreed to support software from Apple called CarPlay, as well as a competing product from Google, called Android Auto, in part to address a troubling trend: according to research from the National Safety Council, a nonprofit group, more than 25 percent of road accidents are a result of a driver's fiddling with a phone. Hyundai's car, which goes on sale this summer, will be one of the first to support CarPlay, and the carmaker had made the Sonata available so I could see how the software works.

CarPlay certainly seemed more intuitive and less distracting than fiddling with a smartphone behind the wheel. Siri felt like a better way to send texts, place calls, or find directions. The system has obvious limitations: if a phone loses the signal or its battery dies, for example, it will stop working fully. And Siri can't always be relied upon to hear you correctly. Still, I would've gladly used CarPlay in the rental car I'd picked up at the San Francisco airport: a 2013 Volkswagen Jetta. There was little inside besides an air-conditioning unit and a radio. The one technological luxury, ironically, was a 30-pin cable for an outdated iPhone. To use my smartphone for navigation, I needed a suction mount, an adapter for charging through the cigarette lighter, and good eyesight. More than once as I drove around, my iPhone came unstuck from the windshield and bounced under the passenger seat.

Android Auto also seemed like a huge improvement. When a Google product manager, Daniel Holle, took me for a ride in another Hyundai Sonata, he

plugged his Nexus smartphone into the car and the touch screen was immediately taken over by Google Now, a kind of super-app that provides recommendations based on your location, your Web searches, your Gmail messages, and so on. In our case it was showing directions to a Starbucks because Holle had searched for coffee just before leaving his office. Had a ticket for an upcoming flight been in his in-box, Holle explained, Google Now would've automatically shown directions to the airport. "A big part of why we're doing it is driver safety," he said. "But there's also this huge opportunity for digital experience in the car. This is a smart driving assistant."

CarPlay and Android Auto not only give Apple and Google a foothold in the automobile but may signal the start of a more significant effort by these companies to reinvent the car. If they could tap into the many different computers that control car systems, they could use their software expertise to reimagine functions such as steering or collision avoidance. They could create operating systems for cars.

Google has already built its own self-driving cars, using a combination of advanced sensors, mapping data, and clever navigation and control software. There are indications that Apple is now working on a car too: though the company won't comment on what it terms "rumors and speculation," it is hiring dozens of people with expertise in automotive design, engineering, and strategy. Vans that belong to Apple, fitted with sensors that might be useful for automated driving, have been spotted cruising around California.

After talking to numerous people with knowledge of the car industry, I believe an Apple car is entirely plausible. But it almost doesn't matter. The much bigger opportunity for Apple and Google will be in developing software that will add new capabilities to any car: not just automated driving but also advanced diagnostics and over-the-air software upgrades and repairs. Already, a button at the bottom of the Android Auto interface is meant for future apps that could show vehicle diagnostics. Google expects these apps to be made by carmakers at first, showing more advanced vehicle data than the mysterious engine light that flashes when something goes wrong. Google would like to make use of such car data too, Holle says. Perhaps if Android Auto knew that your engine was overheating, Google Now could plan a trip to a nearby mechanic for you.

"It doesn't make sense that the first thing you do is buy a $5 suction cup for your phone."

At least for now, though, the Google and Apple services essentially can read only basic vehicle data like whether a car is in drive, park, or reverse. Carmakers won't let those companies put their software deeper into the brains of the car, and whether that will change is a crucial question. After all, modern cars depend on computers to run just about everything, from the entertainment console to the engine pistons, and whoever supplies the software for these systems will shape automotive innovation. Instead of letting Apple and Google define their future, carmakers are opening or expanding labs in Silicon Valley in an attempt to fend off the competition and more fully embrace the possibilities offered by software.

The car could be on the verge of its biggest reinvention yet—but can carmakers do it themselves? Or will they give up the keys?

Cultural shift

Cars are far more computerized than they might seem. Automakers began using integrated circuits to monitor and control basic engine functions in the late 1970s; computerization accelerated in the 1980s as regulations on fuel efficiency and emissions were put in place, requiring even better engine control. In 1982, for instance, computers began taking full control of the automatic transmission in some models.

New cars now have between 50 and 100 computers and run millions of lines of code. An internal network connects these computers, allowing a mechanic or dealer to assess a car's health through a diagnostic port just below the steering wheel. Some carmakers diagnose problems with vehicles remotely, through a wireless link, and it's possible to plug a gadget into your car's diagnostic port to identify engine problems or track driving habits via a smartphone app.

However, until now we haven't seen software make significant use of all these computer systems. There is no common operating system. Given that carmakers are preventing CarPlay or Android Auto from playing that role, it's clear that the auto companies are taking a first crack at it. How successful they are will depend on how ambitious and creative they are. Roughly 10 minutes north of Google's office, I got to see how one of the oldest car companies is beginning to think about this possibility.

Ford opened its research lab in Palo Alto in January. Located one door down from Skype and just around the cor-

Timeline of Automobile Computerization

1966

GM engineers propose using radio relay stations and sensors buried in roads to give drivers directions and traffic updates.

1978

Electronic cruise control is made possible through a Motorola processor.

1981

The engines in all GM models have a Motorola microcomputer that controls the carburetor and fuel injection.

1983

Electronic stability control is introduced in the Toyota Crown.

1987

First touch screen appears, in a Buick Riviera.

1990s

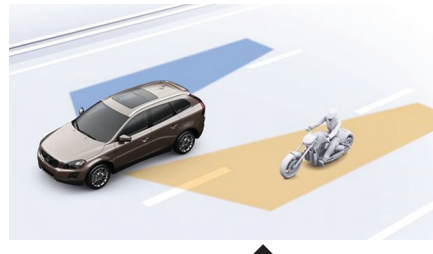
Electronics expand into seat motors, instrument panel lighting, and car locks.

1993

A new international standard lets computer systems embedded in cars talk to each other.

1995

The first satellite navigation system is released: GuideStar for the Oldsmobile Eighty Eight.



1996

A system for reading car performance data, known as ODBII, becomes standard on all vehicles.

2007

Blind-spot warning appears on a Volvo S80.

2013

The Infiniti Q50 is the world's first steer-by-wire car.

2013

Tesla's Model S is introduced. It has a 17-inch touch screen, wireless connectivity, and over-the-air upgrades.

ner from Hewlett-Packard, it looks like a typical startup space. There are red beanbags, 3-D printers, and rows of empty desks, which the company hopes to fill with more than a hundred engineers. I met a user-interface designer named Casey Feldman. He was perched atop a balance board at a standing desk, working on Ford's latest infotainment system, Sync 3. It runs software Ford has developed, but the automaker is working on ways to hand the screen over to CarPlay or Android Auto if you plug in a smartphone. Feldman was using a box about the size of a mini-fridge, with a touch screen and dashboard controls, to test the software. He showed how Sync 3 displays a simplified interface when the car is traveling at high speed.

Ford's first touch-screen interface, called MyFord Touch, didn't go well. Introduced in 2010, it was plagued by bugs, and customers complained that it was overcomplicated. When Ford dropped from 10th to 20th place in *Consumer Reports*' annual reliability ratings in 2011, MyFord Touch was cited as a key problem. The company ended up sending out more than 250,000 memory sticks containing software fixes for customers to upload to their cars.

Besides running apps like Spotify and Pandora Radio, Sync 3 can connect to a home Wi-Fi network to receive bug fixes and updates for the console software. Ford clearly hopes that drivers will prefer its system to either CarPlay or Android

Auto, and it's doing its best to make it compelling. "It's a cultural shift," says Dragos Maciuca, the lab's technical director. The lab wants to incorporate "some of the Silicon Valley attitudes, but also processes" into the automotive industry, he says. "That is clearly going to be very challenging, but that's why we're here. It doesn't make sense that you buy a car, and the first thing you do is buy a $5 suction cup for your phone."

Ford has been ahead of many automakers in its experimentation. It has come out with a module known as Open XC, which lets people download a wide range of sensor data from their cars and develop apps to aid their driving. A Ford engineer used it to create a shift knob for cars with manual transmission so that the stick lights up or buzzes when it's time to change gears. But Open XC has not taken off widely, and despite Ford's best efforts, the company's overall approach still seems somewhat conservative. Maciuca and others said they were wary of alienating Ford's vast and diverse customer base.

In February, meanwhile, the chip maker Nvidia announced two new products designed to give cars considerably more computing power. One is capable of rendering 3-D graphics on up to three different in-car displays at once. The other can collect and process data from up to 12 cameras around a car, and it features machine-learning software that can help collision-avoidance systems or even automated driving systems recognize certain obstacles on the road. These two systems point to the huge opportunity that advanced automotive sensors and computer systems offer to software makers. "We're arguing now you need supercomputing in the car," Danny Shapiro, senior director of automotive at Nvidia, told me.

If anyone could find a great use for a supercomputer on wheels, it's Chris Gerdes, a professor of mechanical engineering who leads Stanford University's Dynamic Design Lab. Gerdes originally studied robotics as a graduate student, but while pursuing a PhD at Berkeley, he became interested in cars after rebuilding the engine of an old Chevy Cavalier. He drove me to the lab from his office in an incredibly messy Subaru Legacy.

Inside the lab, students were working away on several projects spread across large open spaces: a lightweight, solar-powered car; a Ford Fusion covered in sensors; and a hand-built two-person vehicle resembling a dune buggy. Gerdes pointed to the Fusion. After Ford gave his students a custom software interface, they found it relatively easy to get the car to drive itself. Indeed, the ability to manipulate a car through software explains why many cars can already park themselves and automatically stay within a lane and maintain a safe distance from the vehicle ahead. In the coming years, several carmakers will introduce vehicles capable of driving themselves on highways for long periods. "There are so many things you can do now to innovate that don't necessarily require that you bend sheet metal," Gerdes said as we walked around. "The car is a platform for all sorts of things, and many of those things can be tried in software."

The dune-buggy-like car takes programmability to the extreme. Virtually every component is controlled by an actuator connected to a computer. This means that software can configure each wheel to behave in a way that makes an ordinary road feel as if it were covered with ice. Or, using data from sensors fitted to the front of the car, it can be configured to help a novice motorist react like a race-car driver. The idea is to explore how computers could make driving safer and more efficient without taking control away from the driver completely.

In fact, one small carmaker—headquartered in Silicon Valley—shows how transformational an aggressive approach to software innovation could be.

Drive safely

Tesla Motors, based in Palo Alto, has built what's probably the world's most computerized consumer car. The Model S, an

Operating Systems for Cars

	CarPlay	Android Auto	QNX	Windows E.A.	Tesla OS	Open XC
Made by	Apple	Google	BlackBerry	Windows	Tesla	Ford
Where it runs	iPhone	Android device	Embedded	Embedded	Embedded	Open XC device
Supported by	Most manufacturers	Most manufacturers	Audi, Porsche, Toyota, Honda, Ford, General Motors	Ford, Nissan, Kia, Fiat	Tesla	Ford

electric sedan released in 2012, has a 17-inch touch-screen display, a 3G cellular connection, and even a Web browser. The touch screen shows entertainment apps, a map with nearby charging stations, and details about the car's battery. But it can also be used to customize all sorts of vehicle settings, including those governing the suspension and the acceleration mode (depending on the model, it goes from "normal" to "sport" or from "sport" to "insane").

Every few months, Tesla owners receive a software update that adds new functions to their vehicle. Since the Model S was released, these have included more detailed maps, better acceleration, a hill-start mode that stops the car from rolling backwards, and a blind-spot warning (providing a car has the right sensors). Tesla's CEO, Elon Musk, has said a software patch released this summer would add automated highway driving to suitably equipped models.

These software updates can do more than just add new bells and whistles. Toward the end of 2013, the company faced a safety scare when several Model S cars caught fire after running over debris that ruptured their battery packs. Tesla engineers believed the fires to be rare events, and they knew of a simple fix, but it meant raising the suspension on every Model S on the road. Instead of requiring owners to bring their cars to a mechanic, Tesla released a patch over the airwaves that adjusted the suspension to keep the Model S elevated at higher speeds, greatly reducing the chance of further accidents. (In case customers wanted even more peace of mind, the company also offered a titanium shield that mechanics could install.)

Tesla's efforts show how making cars more fully programmable can add value well after they roll out of the showroom. But software-defined vehicles could also become a juicy target for troublemakers.

In 2013, at the DEF CON conference in Las Vegas, two computer-security experts, Charlie Miller and Chris Valasek, showed that they could hijack the internal network of a 2010 Toyota Prius and remotely control critical features, including steering and braking. "No one really knows a lot about car security, or what it's all about, because there hasn't been a lot of research," Miller told me. "It's possible, if you went out and bought a 2013, they've done huge improvements—we don't know. That's one of the scary things about it."

A few real-world incidents point to why car security might become a problem. In February 2010, dozens of cars around Texas suddenly refused to start and also, inexplicably, began sounding their horns. The cars had been fitted with devices that let the company that leased them, the Texas Auto Center, track them and then disable and recover them should the driver fail to make payments. Unfortunately, a disgruntled employee with access to the company's system was using those gadgets to cause havoc.

I asked Gerdes whether concerns over reliability and security could slow the computerization of cars. He said that didn't have to be the case. "The key question is, 'How fast can you move safely?'" he says. "The bet that many Silicon Valley companies are making—and that many car companies are making with their Valley offices—is that there are ways to move faster and still be safe."

Ultimately, the opportunities may well outweigh such concerns. Tesla's efforts point to how significant software innovation could turn out to be for carmakers. Tesla is even experimenting with connecting the forthcoming autopilot system to the car's calendar, for example. The car could automatically pull up outside the front door just in time for the owner to drive to an upcoming appointment.

One of the cars at Stanford's Dynamic Design Lab.

Perhaps this also explains why Apple and Google are now dabbling in vehicle hardware: so they can fully own some people's driving time even before carmakers decide to open up more aspects of their vehicles. "Clearly Apple and Google would love to be the ones who have the operating system for these future cars," Gerdes says.

As I drove back to the San Francisco airport, my VW Jetta felt more low-tech than ever. The ride was fairly peaceful, with the Santa Cruz Mountains looming in the distance. Even so, after so much driving, I would've been glad had Siri offered to take over.

Will Knight is MIT Technology Review*'s senior editor for AI.*

STEPHEN RUSSELL, STANFORD UNIVERSITY DYNAMIC DESIGN LAB

Michelle Dipp, CEO of OvaScience

Slowing the Biological Clock

For years researchers believed that women were born with all the eggs they would ever have. That—and the fact that the quality of the eggs diminishes when a woman reaches her 40s—meant infertility was inevitable past a certain age. But in 2004, Jonathan Tilly and other researchers at Massachusetts General Hospital showed that ovaries also contain egg precursor cells, which might, in theory, mature into new eggs or boost the health of existing ones. Now OvaScience, which Tilly cofounded—a member of this year's 50 Smartest Companies list—is developing treatments for infertile couples. In its first commercially available approach, energy-producing mitochondria are transferred from egg precursor cells into mature eggs to rejuvenate them. These eggs are then used for in vitro fertilization. In May, the first baby was born to parents who tried this approach. OvaScience CEO Michelle Dipp spoke with *MIT Technology Review* contributing editor Amanda Schaffer.

What need does OvaScience's technology address that regular in vitro fertilization does not?
One in six couples worldwide struggles with infertility, and unfortunately, the standard of care, which is IVF, often fails. Our goal is to address the root cause of infertility and the reason treatment fails, which is frequently unhealthy eggs. We now know that women have egg precursor cells in the outer lining of our ovaries. We are developing several treatments that use these precursor cells. In one treatment, which is now on the market, we add mitochondria to eggs. In another approach, which is still experimental, we move egg precursor cells to the middle of the ovary so that they grow into eggs during IVF. In a third treatment [also experimental], we take the precursor cells and grow them into eggs outside the body.

Should these treatments change the way we think about the biological clock?
As a woman gets older, she still has these fresh, young, healthy egg precursor cells. These cells don't seem to age with time, because they're in an area that lacks a good blood supply, so they lie dormant. I do think that discovery should change our assumptions about fertility and aging.

So how late in life could a woman get pregnant?
It ends up being a doctor-patient conversation about what age they do IVF, and most clinics have certain ways to think about what their age cutoff is. Usually around the time of menopause, it becomes a lot more challenging. Women have to use other hormones in addition to IVF to get pregnant.

Do you see a limit on how many people could benefit from this technology?
More women are waiting to start families. When you look at emerging markets, like in Latin America and the Middle East, more women are going to college, more of them are seeking advanced degrees, more of them are traveling to other countries to get those advanced degrees. They're prioritizing other things. [Because they're older when they try to have children] there's an increase in infertility as well as in IVF rates, and the demand is expected to be even greater in the future. The global market is projected to reach over $20 billion by 2020.

This treatment is expensive—$15,000 on top of the cost of IVF. Won't cost place an important limit on patient access?
It already does with IVF. Many more couples are infertile than seek treatment, because it is paid for out of pocket. [But] a number of doctors offer IVF pro bono in countries where it is hard for patients to gain access.

Your first treatment is not available in the United States. Is the future of the company mainly in other countries?
That's certainly what the market has always dictated in the past. The growth rate of IVF in Europe is about 10 percent. There is no growth in the U.S. That said, the goal is to bring our treatments to women everywhere, and that includes the U.S. But I'm afraid I can't comment on what we would need to do to win regulatory approval here.

How strong is the evidence that your treatment works, considering the absence of randomized controlled trials?
New data show that women who failed previous IVF treatment and then used our approach increased their chance of having a child. We're really excited about that. Because these women had tried IVF already, they served as their own controls.

Fertility treatments are not drugs. Drugs are of course analyzed by a randomized controlled trial, but these are surgical procedures.

LEONARD GRECO

JABIL

Dreaming Big at Jabil's Blue Sky Center

Dream big or go home.

That's the unofficial motto of Jabil's new Blue Sky Center in San Jose, California, where the company is assembling a concentration of brainpower and engineering capabilities that's impressive even by Silicon Valley standards. The center – actually a 100,000-square-foot campus – is designed to serve simultaneously as a showcase and an R&D hub for the global design, manufacturing, and supply chain services giant.

"We named it 'Blue Sky' because we want people to know that the sky's the limit when it comes to innovation," says Joanne Moretti, senior vice president of worldwide marketing at Jabil. "It's fertile ground for innovation, where our top people, our capabilities, our partners, and our customers can all come together to realize their dreams."

Jabil: A Major Player Transforms Itself

Of course, thinking big is nothing new for Jabil, which reported nearly $16 billion in revenues for 2014 and currently ranks 155th on the Fortune 500 list. The company employs more than 180,000 people in 24 countries and works with 17,000 suppliers. Its customer base reads like a *Who's Who* of both big brands and promising startups. Apple, Athos, Crestron, Honeywell, NetApp, Tesla, Tile, Whistle, and Zebra are just a few of the companies that count on Jabil's services.

Jabil designs and builds across the entire digital universe, from device to data center to the cloud. For example: In 2014 it produced 300,000 smartphones a day for one customer and manufactured 15 million wearable and lifestyle devices for another. Other products include smart energy meters, "connected" home devices and clothing for remote health monitoring, and cloud-ready infrastructure, including servers, storage systems, and networks. In addition, Jabil's Nypro division designs health-care products that range from small pharmaceutical devices to large diagnostic and hospital equipment.

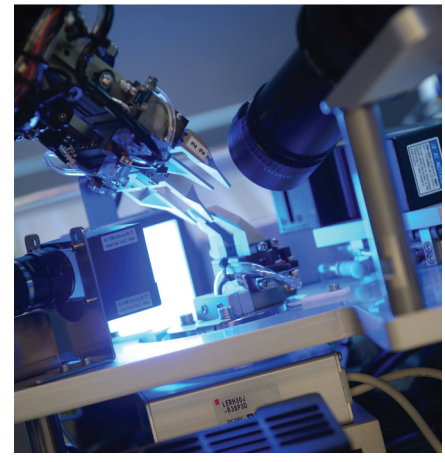
"We enjoy an interesting spot in the technology ecosystem," says Erich Hoch, Jabil's executive vice president for engineering and technology services. "We have direct connections into the top 250 brands in the world across multiple sectors, including top suppliers like Intel. We can all collaborate to help our customers gain differentiation and first-mover advantage."

Founded in 1966, Jabil started out as an electronics manufacturing services (EMS) contract manufacturer. Today, it's repositioning itself as a full-service solution provider, delivering solutions for the entire product lifecycle, from conceptualization to design engineering to development of industrial solutions to manufacturing to distribution.

"Our customers are asking us for more than 'build to order' services," Moretti says. "They want us to come to the table with innovative ideas. The beauty is, we cut across 13 industry sectors, and can cross-pollinate our capabilities from one industry to another to help them gain competitive advantage in the face of accelerating change."

As one example, she cites Jabil's design of a novel hospital feeding tube equipped with a tiny 3-D camera, an LED light, and specialized adhesives that must meet FDA standards. This invention combined four of Jabil's engineering capabilities, Moretti notes: "The four came together to provide unmatched differentiation to our customer in the space."

In an era of growing personalization – that is, tailoring of products to users – and increasing consumerization, Jabil customers expect the company to be agile and fast, Hoch observes. For that reason, Jabil leverages big data and analytics for its factory-automation and 3-D printing processes, all managed through its Intelligent Digital Supply Chain.



Ultimately, three factors set Jabil apart in the marketplace, Moretti explains. "First, we will never compete with our customers. We protect their intellectual property, and their reputations, with our lives." Second, but equally important, is Jabil's ingenious workforce. Finally, there's the company's unified IT backbone, "which gives us 24 x 7 x 365 global visibility and underpins our Intelligent Digital Supply Chain," she concludes.

A New Hub for Innovation

The new Blue Sky Center, launched in April 2015, is where all Jabil's capabilities come together for the benefit of Jabil's customers. Jabil has been moving key employees from all over the world to this new location, where about 350 people work now. "Having most of our experts on one campus will help us get more things done in real time," Hoch says. "It will move the needle for us – and even more so for our customers."

The center also houses Jabil's Intelligent Digital Supply Chain Operations Center, which resembles the bridge of the *U.S.S. Enterprise* of *Star Trek* fame. Jabil's system includes a giant screen that can show any Jabil customer's supply chain in real time. The system identifies high, medium, and low risks in the supply chain, as well as opportunities for optimization. It provides visibility into weather, points of failure, potential labor issues, freight considerations, geopolitical unrest, and changing levels of demands for products. Jabil can assess all those factors to proactively determine the optimal supply-chain configuration for any customer. What's more, Jabil does this modeling at the beginning of the product lifecycle, not as an afterthought, Hoch says. About 60 Jabil customers are already using this system, with new ones coming online almost daily.

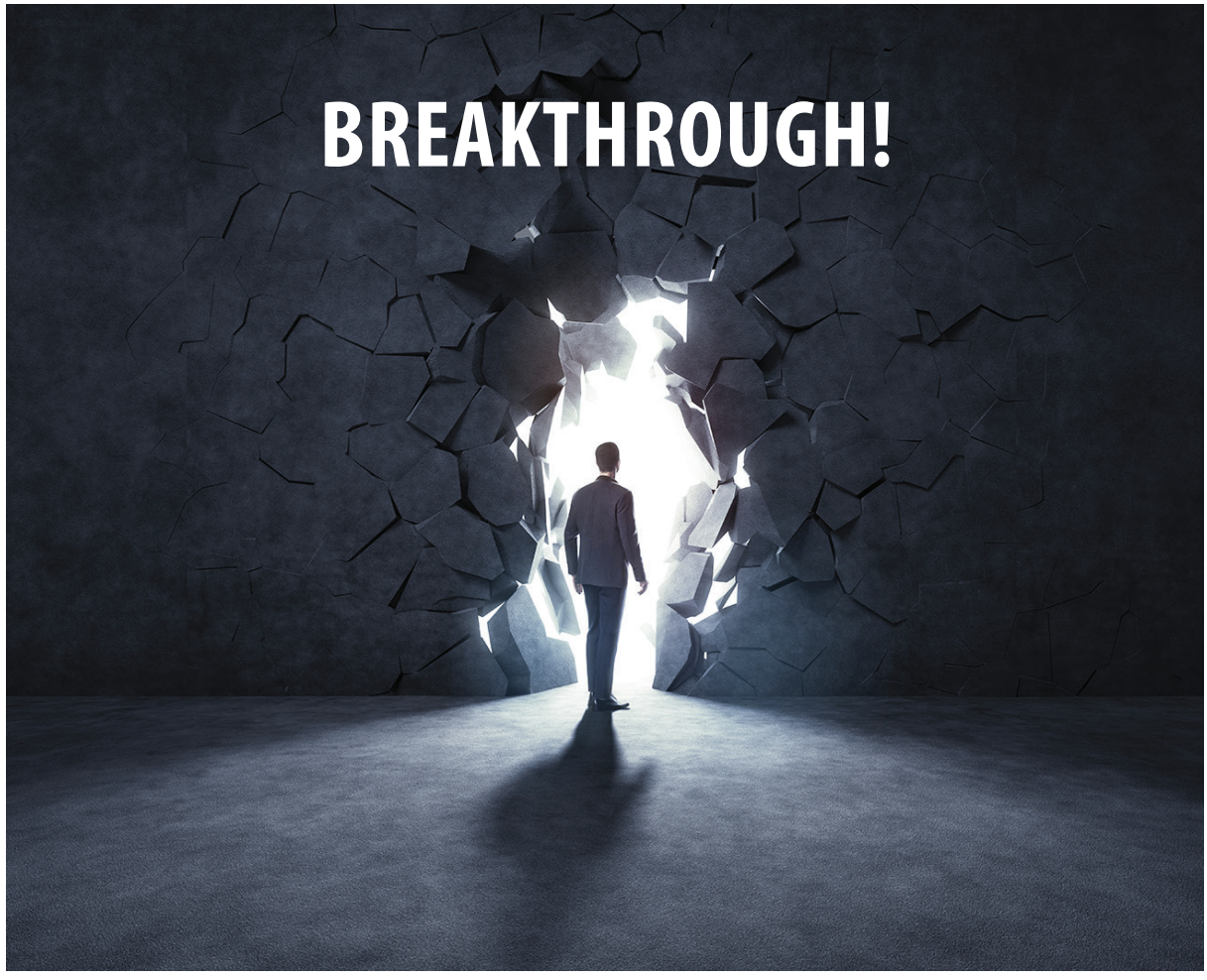
In addition to housing R&D, design, and prototyping activities, Blue Sky also serves as a customer engagement center, Moretti says. The center's Innovation Hall features what Jabil believes is the world's largest curved, full-touch-screen explorer wall. The hall also contains a movie theater, an IoT-enabled city model, and other features reminiscent of a science museum, all intended to illustrate Jabil's vast portfolio of engineering capabilities and simultaneously stimulate its visitors' imaginations.

Ultimately, the Blue Sky Center – like Jabil itself – is about realizing dreams and pushing both engineering and imagination to new heights.

For more information, visit www.jabil.com.

Blue Sky Center offerings include:

- A conceptualization and market-testing lab
- A prototyping center
- An Internet of Things (IoT) partner ecosystem lab
- An automation lab with 3-D printers and robots
- Acoustic chambers
- A process innovation and miniaturization lab
- A full scale, fully equipped hospital room for health care projects
- An adhesives lab



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High-Tech Food Chain

From farm to table, technology could change how we grow, process, distribute, buy, and prepare our food.

GOLDEN COSMOS

The Big Question

Food Technology for All

We may be heading toward a new food economy that's more competitive and innovative.

● For years, the most important food technologies were all about scale. How could we feed a fast-growing population at less expense? By doing everything bigger: food grown on bigger farms was sold by ever-merging global food giants to grocery chains of superstore proportions.

Many of today's food technologies seem to be moving in the opposite direction, toward methods and products that are economical for small farms as well as large corporate ones. This does not mean an end to big food: with the planet's population projected to reach 9.6 billion by 2050, agriculture and food production will still have to achieve a massive scale, with help from technology and innovative research. Still, evolving technologies, including inexpensive sensors, mobile devices, and data analysis, have helped an increasing variety of food companies, retailers, and producers lower their costs and compete in many specialty markets.

9.6 billion
Estimated number of people worldwide who will need to be fed in 2050

This could be the start of a new food economy—one that reflects more competition and more innovation, provides opportunity for a broader group of investors, and is more dynamic and responsive than the industrial model that has dominated for decades.

This Business Report explores the implications of that shift—for financing food startups, for the development of new foods, and even for how we shop and eat.

Between January 2013 and December 2014, 47 funds launched with plans to invest in food and agriculture, as tallied by the online publication *Food Tech Connect*. Venture investment in food-tech startups climbed to more than $1 billion in 2014, according to CB Insights—a significant increase from $288 million in 2013. One focus of Google Ventures and other Silicon Valley investors has been companies taking creative approaches to producing new foods such as vegetable-based beef substitutes, protein bars made with cricket flour, and other products aimed at small but valuable groups of consumers.

Regulation is pushing some of these food innovations as well. In Vevey, Switzerland, the world's largest food company, Nestlé, is using techniques to trick the palate into finding products delicious even with 10 percent less salt and sugar. Several European Union–funded programs are using genetic and molecular research to find new ways to confirm food safety and authenticity.

On the farm, software and data analysis could make agriculture more affordable for operations of all sizes. Today every John Deere tractor, sprayer, and combine comes equipped to wirelessly communicate information about where it is, what it has planted, and more. By combining this information with data generated by soil sensors and weather reports, farmers could find ways to use water, seed, and fertilizer more efficiently, lowering their costs enough to more than pay for the technology investment while maintaining or even improving yields.

Small-scale livestock producers have been some of the earliest supporters of Vital Herd, a technology in trials that measures and transmits key metrics of bovine health every 15 minutes—heart rate, respiration, temperature, and the contraction rate of the animal's rumen. All this is measured by a four-inch-long "e-pill" the cow has swallowed. Today a herd's health is monitored largely by farmer observation. But with this new flow of data, farmers might be more likely to identify a sick animal before illness spreads, thus minimizing the use of antibiotics. Henden Manor Estates, which keeps 500 milk cows and younger Holstein Friesians in Kent, southeast of London, is an investor. Says its owner, Roni Lovegrove: "If they get it right, it will be so transformative."

New technologies are being tested in parts of the food chain closer to our kitchens, too. They form the basis for meal-prep sites like Plated, HelloFresh, and Blue Apron, which offer recipes and doorstep delivery of ingredients. These sites are competing with established supermarket giants, forcing them to rethink how they sell food. *—Nanette Byrnes*

Case Study

Supermarkets, Startup Style

Companies are using technology to make food shopping more convenient. Is this how we will all shop in the future?

● The way Americans eat is in flux. Some research suggests that after a long trend of trading home-cooked meals for takeout and restaurant fare, Americans may be returning to their kitchens and choosing more nutritious food.

Shopping for food is changing too, and new technology-fueled models are emerging to serve this new style of eating, though they still account for just a small fraction of total food sales. Straightforward websites and apps that make it easy to plan and shop for meals are challenging supermarkets to rethink how they sell food.

Meal-preparation sites like Plated, HelloFresh, and Blue Apron have gained millions in venture capital. They offer websites that feature recipes designed by chefs, and then they deliver exactly the ingredients needed to make them in a refrigerated box to a customer's doorstep each week. HelloFresh and Blue Apron both say they are delivering more than one million meals per month to subscribers, who typically receive at least three meals per week.

THE NEW FOOD CHAIN

Today online food markets and grocery and meal kit delivery services are offering new ways to shop for food.

	Headquarters	Year founded	Type	Funding	Business model
BLUE APRON	New York	2012	Meal kit	$58 million; investors include Stripes Group and Joseph Sanberg	Customers choose three chef-inspired meals a week to feed two or four people. A two-person subscription costs $59.99 a week. Delivers more than two million meals a month, with service to most U.S. cities. Also offers an online cookware marketplace.
PLATED	New York	2012	Meal kit	$21.4 million; investors include Slow Ventures (founded by former Facebook executives) and Founder Collective	For prices starting at $12 a plate, customers get a box full of ingredients for chef-designed meals delivered to their door. Subscribers must choose a minimum of two meals per week for two people.
HELLOFRESH	Berlin	2012	Meal kit	$196 million; investors include Berlin's Rocket Internet and London's Phenomenon Ventures	Ingredients for chef-inspired recipes are delivered at prices starting around $9 a plate for vegetarian meals, more for boxes including meat. Available across the United States and in the U.K., Austria, Belgium, Germany, the Netherlands, and Australia.
INSTACART	San Francisco	2012	General delivery	$275 million; investors include Comcast Ventures, Sequoia Capital, and Kleiner Perkins Caufield & Byers	People in 15 U.S. cities can choose items online from local stores for same-day delivery in as little as one hour. Delivery costs range from $3.99 to $9.99. Instacart tries to provide prices equal to the store's, but they are sometimes higher.
FRESHDIRECT	Long Island City, New York	1999	Online marketplace	Not disclosed	Online grocery delivery to New York City and Philadelphia areas, as well as parts of Delaware, Connecticut, and New Jersey.
PEAPOD	Skokie, Illinois	1989	Online marketplace	Went public in 1997; owned by the Dutch firm Ahold since 2001	Partnering with local grocers, has fulfilled more than 29 million online orders for home delivery or in-store pickup in 24 Midwest and East Coast U.S. markets. Serves more than half a million customers and offers over 15,000 items.
GOOD EGGS	San Francisco	2011	Online marketplace	$31.5 million; investors include the Westly Group, Index Ventures, and Sequoia Capital	Farmers use Good Eggs software to set their own prices and take online orders, and then deliver the goods to a Good Eggs center in San Francisco, Los Angeles, New York, or New Orleans for the company to deliver.

Convenience comes at a price. At Blue Apron, each individual portion for a two-person plan starts at $9.99; at Plated, a "plate" starts at $12.

Instacart, which delivers food from local grocery stores in 15 U.S. cities, charges anywhere from $3.99 to $9.99 plus the cost of the food, depending on how big the order is and how quickly the customer wants it delivered.

"It's been great but expensive," says Rence Delino, a frequent Instacart customer in Washington, D.C. He likes that he usually receives deliveries within an hour and a half from any grocery store in the area (deliveries at the cheapest price usually come within two hours, but shoppers can pay more for service within an hour), and he appreciates the cheerful personal shoppers who call to confirm any replacement items they'll pick up if something on the shopping list is out of stock.

Delino opted for a $99 membership that allows frequent shoppers to get free deliveries for a year on orders of more than $35. But some items cost significantly more when he orders them through Instacart than they would if he bought them himself. One is English muffins, which carry a regular price tag of $4.29 at his local store (in-store promotions can bring them as low as 99 cents per pack) but have cost more than $5 when purchased through the app, he says.

The company says it tries to keep prices on the app the same as in the store, thanks to partnerships with more than 60 retailers. But some grocers' online prices may differ from prices in store. Instacart recently changed its interface to make its pricing more transparent.

Facing this new trend, some supermarkets are testing out technologies that similarly help get customized food orders delivered quickly. When home chefs find a recipe they'd like to try on the free recipe discovery app and website Yummly, they can export the shopping list to Instacart and arrange a delivery from a local store. Meanwhile, the online grocery store Peapod has started delivering rec-

ipe ingredients for the meal-planning site Gatheredtable.

Supermarkets are also looking for ways technology can improve shopping in stores, which is how most Americans still buy their food. Indiana-based Marsh Supermarkets has teamed with marketing company inMarket to install beacons at its 77 stores. Shoppers can see a layout of their favorite store through a smartphone app. When they add an item to their shopping list, that item appears on the map. Beacons can send location-appropriate promotions to shoppers' phones.

In the future, the chain plans to experiment with apps for the Apple Watch, among them a notification from a beacon in the store to alert you if you are nearing the checkout counter without having crossed an item off your in-app shopping list. *—Kristin Majcher*

Case Study

Mobile App Brings Dynamic Pricing to the Dinner Table

A new app is testing whether the economic theory behind Uber and Priceline can work in restaurants, too.

● In Texas, a state whose gastronomical classics include barbecue, Tex-Mex, and chicken-fried steak, diners are testing something new. An Austin-based startup called Taste Bud has launched a restaurant app that puts its own spin on the dynamic pricing models of ride-sharing apps Uber and Lyft.

Launched last fall, Taste Bud offers discounts at 30 local restaurants. The deals are updated in real time depending on supply and demand.

The idea is that you save less during the noon rush than you would when restaurants are not as busy. The app targets money-conscious college students, with all but two of the Taste Bud restaurant choices within blocks of the University of Texas at Austin. Taste Bud joins a handful of similar services beginning to operate in other cities, among them RezGuru, TableGrabber, Leloca, Hooked, and Table8.

With Taste Bud, each restaurant designs the deals it wishes to offer, including the minimum and maximum prices and the times at which the offer is valid. Then Taste Bud's algorithm works within those parameters, frequently recalculating the offer's value on the basis of factors like time of day, supply and demand at that moment, and a user's buying history and proximity to the restaurant. Offers then filter onto the app's home screen, where each user can sort them by distance, price, or location. Once the user accepts an offer, the price is locked into place and the app generates an electronic coupon that is redeemable at the restaurant. Taste Bud takes a cut of the discounted offer.

During the final weekend of South by Southwest, an event that attracts around 85,000 registrants and has restaurants packed, I went to Trudy's Tex-Mex Restaurant and Bar, a longtime staple in Austin. Half an hour before I arrived, I used Taste Bud to purchase $15 worth of food for $11.01, or 26.6 percent off, during one of the busiest times for a restaurant—the weekend dinner rush.

When I tried to redeem my coupon, the bartender was unfamiliar with Taste Bud. She consulted a supervisor, who had heard of the app but struggled for around 20 minutes to process the transaction. In the end, I did save the $4.

Further testing during the week following South by Southwest showed that the best deals did seem to be available at off hours. A coupon for $10 worth of food for $6.78, or 32 percent off, went to a Tuesday-night dinner of Kosmic Karma pizza from the hippie-themed pizzeria Mellow Mushroom, a popular spot for college students.

Around 2:30 P.M. the next day, in the midafternoon doldrums, I got a better deal—$10 worth of food for $6.35, or 36.5 percent off—from the national chain Qdoba. In total, I saved almost $11 over three meals, and I had no trouble redeeming my last two coupons.

The pricing seemed to work as expected on my three meals. But to broaden this limited data set, I recorded every discount offered during peak and nonpeak hours on a single weekday. I got similar results. At 8:45 A.M., the average discount was 33 percent. By the height of the lunchtime rush, the average fell to 30 percent, only to soar to 47 percent by midafternoon. The dinner rush sliced the average to 29 percent.

For restaurants, the app boosts business during nonpeak hours, helps them manage perishable inventory, and tracks repeat customers.

For restaurants, the app boosts business during nonpeak hours, helps them manage perishable inventory, and tracks repeat customers. According to Marcelo Vieira, CEO and cofounder of Taste Bud, restaurants are seeing about a 20 percent return on their investment in the first 30 days.

Wade Guice, co-owner of ATX Boudain Hut, a food truck and trailer offering Cajun cuisine that has been using Taste Bud since September, says the app provides a cheap way to advertise. He estimates that the truck processes 30 transactions a week via Taste Bud, and though he's offering discounts of 10 to 20 percent, he says, "I'm still making my money off of it, too."

Though the algorithm does seem to be doing its job, it's not yet clear how appealing Taste Bud is to diners.

One recent evening, only 90 minutes until closing, popular Trudy's had sold just two of its 50 available coupons for the day. My waiter at Mellow Mushroom said that even among their price-conscious customers, only two to three people use the app there each day. *—Andy East*

Case Study

The Nestlé Health Offensive

The world's largest food company tries to overcome technical challenges and popular tastes to make its food healthier.

● For people concerned about public health, it's fashionable to lay the responsibility for our problems at the doorstep of the food industry, which like any other industry must demonstrate growth every quarter. That means selling more packaged food, which is generally high in sugar, salt, and fat to make it more "craveable," to use an industry term, or "addictive," to use the critics'.

Could the food industry engage in, as the public-health community would put it, "harm reduction"? Certainly, big industry has the technical and marketing expertise to do so—skills that far surpass those of any farmer, produce consortium, or artisanal business. And in fact, large food companies such as PepsiCo and Wal-Mart, the largest grocer in the United States and contractor to many factories that produce its private-label food lines, have started talking about producing and selling healthier foods. To varying extents, they're actually doing it. Such changes come as companies keep a weather eye on the flattening sales of full-sugar soda and the steady declines at McDonald's, while trying to stay a half-step ahead of possible government regulation.

The trick for a large company is to make meaningful change in the healthfulness of the food it produces—not just in a few specialty fruit juices, but across the range of its products—and to do it without scaring off buyers. The question is always what will happen if customers don't like "better-for-you" alternatives. PepsiCo, which said in 2008 that it expected its proportion of revenue from what it called "nutrition" products to double by 2020, has seen the level stubbornly stay at 20 percent of total sales.

The world's largest food company by revenue, Nestlé is famous for Crunch and Kit Kat bars and owns dozens of food brands not particularly noted for their nutritional value. In 2005, looking closely at a series of recommendations from the World Health Organization (headquartered in Geneva, an hour from the Nestlé world headquarters in Vevey, Switzerland), it branded itself as a nutrition, health, and wellness company; it later implemented an initiative to reduce sugar, sodium, and saturated fat across its entire product line by the end of 2016. In 2014 alone, it claimed to have reformulated—"renovated," in its own parlance—10,812 of the products that its 2,000 separate brands made in more than 442 factories in 86 countries.

I first visited the Nestlé Research Center, just outside Lausanne, Switzerland, three years ago. In airy white campus-like buildings that house offices and, mostly, laboratories, more than 600 people, 250 of whom earned PhDs in more than 50 countries, collaborate with more than 50 universities to conduct research into food composition, physiology, taste perception, and health. I was shown skull-shaped helmets covered with electrodes to measure which parts of the brain most strongly registered concentrations of salt and sugar and hotel-like accommodations where people would stay for a few days eating controlled diets. On a second visit, in March, I was given a tablet of plain and then citrus-flavored chocolate and told to chew while my mouth and nose were hooked up to tubes that measured which flavor components I started exhaling first (the citrus spiked fast).

But it wasn't until my recent visit that I heard about the "Nestlé Nutritional Foundation"—not the charitable feel-good arm it sounds like but a way to

In 2013, Nestlé began talking to the scientific community about a new set of nutrition commitments aimed at reducing the salt and sugar in its products.

REBEKKA DUNLAP

improve its products' nutritional value. In 2013, Nestlé began talking with the scientific community about its nutritional goals, seeking reaction to its newly calculated target levels of sodium, sugar, saturated fat, iron, and vitamins, among other ingredients. Those WHO-influenced targets included a commitment to reduce the average sugar and sodium content in all Nestlé products by 10 percent between 2014 and 2016. Most of the company's efforts fall under the industry term "stealth health," meaning changes that make food more nutritious without necessarily being promoted that way. This approach means not talking about improvements that consumers will read as providing less flavor and value for their money: people might be put off by claims like "lower fat" and "less salt" in pizzas or "less sugar" in chocolate bars.

10%
Amount by which Nestlé aims to cut the sugar and sodium in its products by 2016

Packaging is one form of stealth. Nestlé is reducing the size of Kit Kat bars to bring down the calories and fat in each portion. (Some say that making portion sizes smaller is also a way to charge the same amount of money for less food.) In Canada, Nestlé has divided its small boxes of Smarties, small colored discs of chocolate, into three compartments, to make it plainly visible that the box contains three servings—in contrast to the typical approach of displaying low per-serving calorie counts on products even though consumers often eat the whole package at one time. More changes to "confectionery" include a recent pledge to remove all artificial dyes and colorings from candy in the United States—a change that can leave products duller-looking (beet coloring for strawberry Nesquik, rather than Pepto-Bismol pink) but also reassure parents. The search to find substitutes began in response to consumer demand, the company says, but there was government pressure too: the United Kingdom and the European Union regulate artificial colorings in candy. The United States doesn't have a parallel ban, but Nestlé could get ahead of one here by using the changes it tested in England. Most of the changes in the Nutritional Foundation guidelines are being made ahead of possible government regulation.

Changing recipes is harder, of course, than changing packaging or even colorings. Reducing some ingredients, like sugar, is relatively straightforward. "Renovating" Nesquik meant finding bulking agents like cocoa powder, its main substitute for sugar, to give consumers the same flavor and texture. This meant adjusting other flavors, like vanillin. It also meant using a technique that has worked for some but not all companies when cutting sodium: successive stepwise reductions so that consumers hardly perceive a change or can't tell at all. And it meant borrowing technology from other Nestlé products—in this case, aerating the powder to give it the appearance of bulk using the process for Aero, a popular chocolate bar in Europe that has hundreds of tiny bubbles, like a more sophisticated Crunch bar. The average sugar content in one portion of Nesquik was 17.2 grams in 2000; in 2014, it was 10.6 grams, a 38 percent reduction. By changing just Nesquik, Nestlé has reduced its use of sugar worldwide by more than a million kilograms since 2014, according to Jörg Spieldenner, head of public health nutrition for Nestlé, and colleagues who had worked on its reformulation.

Sodium is more difficult to replace than sugar, and consumers can be stubborn in their liking for fat. Pizza, one of the packaged foods most frequently marketed to children, is high in both. Taking out sodium and adding herbs, spices, and vegetables to give people the flavor they want turned out to be easier in the case of Nestlé's upscale pizza line, California Pizza Kitchen, than its lower-priced brand, DiGiorno. For CPK, Nestlé increased the size of the tomato slices, added herbs to the sauce in place of sodium, and used smaller amounts of more-aged cheese to give people the idea of the same sharp flavor. The results reduced sodium by 20 percent.

But sodium often has a structural function, not just flavor, and in those cases it's trickier to reduce. Forms of sodium found in baking powder rather than table salt, for instance, put the rise in DiGiorno "Rising Crust" pizzas. Nestlé didn't try to find another leavening agent: it found a way to use a simpler form of sodium, bicarbonate (baking soda), and less of it, by using enzymes to change the strength of the dough—that is, the protein content, which affects the amount of time a dough needs to rise and the amount of leavening it requires.

For the thick blanket of cheese that Nestlé technicians from other countries say is a peculiarly American habit that customers don't want to break, Nestlé is borrowing techniques from other divisions. It not only works with cheesemakers to increase aging time to sharpen the taste but also uses emulsifying techniques from its sauce products and an aeration technique from its Dreyer's ice cream plants, both of which can reduce calories while providing similar feelings of texture and satiety (and, some would say, let manufacturers charge more for air).

The trick for a large company is to make meaningful change in the healthfulness of the food it produces—not just in a few specialty fruit juices, but across the range of its products—and to do it without scaring off buyers.

Many, many smaller and boutique companies are staking their new product lines on claims of fresher, less-processed, lower-calorie food, of course. But it is the often quiet changes made at big companies that can have more of an effect on people's health.

More people are eating their foods.

—Corby Kummer

Technology

Robots Start to Grasp Food Processing

Advances in robotics make it possible to automate tasks such as processing poultry and vegetables.

● It is less striking than Deep Blue's victory over chess champ Garry Kasparov, but Richard van der Linde says that his robotic hand's mastery at picking up cabbage is something of a milestone for machines. With the aid of five cameras, plus sensors in its wrist to monitor the resistance it encounters, the three-fingered gripper can carefully pick up a cabbage, reorient it, and place it into a machine that removes the core. "In industry, only humans can do that at the moment," says van der Linde.

His company Lacquey, based in Delft, the Netherlands, is working with FTNON, a manufacturer of food-processing equipment, to get the technology ready to go to work inside the giant chillers where today humans process cabbage, lettuce, and other produce for packaging. Lacquey is also testing versions for other sorts of jobs, such as packaging tomatoes, peppers, and mangoes.

The company's progress is an example of how advances in robotic manipulation technology are opening up new jobs for robots in the food-processing business. Solid, hard, identical objects such as car parts are easy for robots to move around. But delicate, flexible, naturally variable objects such as meat, fruit, and vegetables require much more sophisticated sensing and manipulation.

Interest is driven partly by the potential to cut labor costs, just as in other industries. But food-processing companies also see robotics as a way to increase safety, says Gary McMurray, who leads the Food Processing Technology division at the Georgia Tech Research Institute. "Anywhere you have people in there handling food, they make mistakes from time to time," he says. Incidents where meat or vegetables become contaminated with, say, *E. coli* or *Listeria* are costly to a food processor. A 2015 study found that on average, meat recalls wiped $109 million from a public food-processing company's value within five days of their announcement. Though figures are not available for the specific number of cases originating from contamination at a food-processing plant, the Centers for Disease Control estimates that 128,000 Americans are hospitalized with food-borne illness from all causes each year, and of those, 3,000 die.

Delicate, flexible, naturally variable objects such as meat, fruit, and vegetables require much more sophisticated sensing and manipulation than solid, hard, identical ones like car parts.

McMurray's research group is currently developing two systems for the poultry industry. One can grasp a chicken carcass moving along a production line and cut the shoulder tendons in preparation for the removal of the breasts and wings. That system can already match the average yield of a human worker. In a second project, a low-cost two-armed robot called Baxter, produced by Rethink Robotics and designed to work safely alongside humans, is being programmed to place poultry carcasses onto the cone-shaped holders that carry them through a processing plant.

Both systems rely on visual and physical feedback. For example, the cutting robot uses a 3-D vision system to estimate the location of a chicken's joints and tendons. It then uses sensors on its knife to "feel" whether it is cutting meat or bone. "Working with these wet, deformable, slippery objects is challenging, but it seems to be doable," says McMurray.

Getting a robot to do a task like that well usually requires engineers to carefully program in specific techniques and commands. But machine-learning software could automate much of that process and make it practical for robots to carry out more complex tasks with a variety of foods, says Ashutosh Saxena, an assistant professor of computer science at Cornell University.

He used that approach to teach a two-armed robot to assemble a simple salad. The robot first went through a training phase in which it used knives, spatulas, forks, and other implements to probe the physical properties of foods including tomatoes, lettuce, and cheddar cheese. Afterward, the robot could figure out for itself how to slice up the elements of the salad and then move them around.

It is unclear when, if ever, it might be possible for a robot to keep pace with a human chef. In the near term, van der Linde says, Lacquey and others have to prove that their machines can match or exceed the pace of humans doing specific tasks on existing production lines.

—Tom Simonite

Technology

Internet of Farm Things

Data from the farm is abundant. Can it be turned into something useful?

● Keith Larrabee's farm sits on 4,000 acres of California's Sacramento Valley, between a coastal range of mountains to the west and the tall Sierra Nevadas to the east. It's an area that traditionally gets much more rain than most of the drought-stricken state. Even so, Larrabee is always worried about the cost and availability of water for his orchards of walnuts and pecans and his 3,000 acres of rice.

Two years ago he began inserting probes five feet deep into the soil of his nut orchards to measure the water concentration foot by foot.

When Larrabee began using such sensors, he had to walk into the fields to read each one individually—a process so laborious that he sometimes did it just once a week. But now, every 15 minutes, readings from the 25 sensors are fed into a network of solar-powered information-gathering stations scattered through the orchard. One of the stations transmits that information to a main database via cell signal. Larrabee uses his smartphone or tablet to log on to see that data, which is available almost instantaneously. Using a software platform called PTC ThingWorx, he sees two color-coded gauges for each sensor—blue means too much water in a given location, red not enough. Combined with data from weather stations around the property, the information helps Larrabee decide when to irrigate, where to do so, and how much water to use, either to maximize growth or to avoid frost. "Everything we do, every time I turn a pump on, everything costs money," he says. "If I can manage my irrigation to exactly what I need, I'm not running the risk of overdoing it. I'm managing the health of the orchard better. I would equate that to a longer life of that orchard, to better crops, better-quality products."

Also: more revenue and more profit.

Companies like Monsanto, tractor maker Deere, and technology giants IBM and Intel, as well as a fast-growing gang of Silicon Valley startups, are hoping for a proliferation of Keith Larrabees: farmers who will see data as an integral part of farming, as important as a reliable tractor or good seed.

A survey conducted last year by the American Farm Bureau Federation, a farm trade association, found that 39 percent of respondents in major corn- and wheat-growing states were using sensor-driven technologies on their farms. "Farming is moving from being an act of intuitive decision making to an act of analytical decision making," says David Friedberg, CEO of Climate Corporation, a data modeling firm that Monsanto bought for $930 million in 2013.

This shift has been made possible in the United States by the proliferation of wireless networks in farm regions and the popularity of smartphones that can deliver information to farmers working in the fields. Major tractor manufacturers have been including hundreds of inexpensive sensors on field equipment for a decade, making it possible to collect data like the topography of each field and the location and depth of each seed planted.

Drones and smaller satellites promise to continue the data generation by making it increasingly possible to capture frequent, high-quality images of small sections of field, at a far lower cost than traditional photography from a piloted plane.

This kind of information can be especially useful when combined with large data sets that government agencies have made available—largely free—in recent years. Among them: troves of historical soil surveys, weather data, and satellite imagery.

Because there are so many sensors, and every data point from a farm sensor has a place and time stamp, the volume of information being generated is enormous, creating a technical challenge for those trying to analyze it. The amount of data from one large farm might be counted in the hundreds of terabytes, according to IBM. Creating the infrastructure to handle that much data will be complicated, says Vin Sharma, a director in Intel's big-data analytics unit.

If companies can create services that turn this abundance of data into money-saving advice, the effect could be crucial for farmers operating on tight margins—in the United States, corn-belt farmers on rented land cleared around $20 an acre in net profit last year. Combining information like localized weather forecasts with details about topography, water levels in the soil, and the seed that has been planted in a field, a company like Climate Corporation will advise farmers about how much fertilizer, an expensive item, to put on a field and when to do so.

But how good is the advice coming from the many companies angling to become the farmer's data advisor? Respondents to the American Farm Bureau Federation survey reported that the technologies they are using have reduced their input costs—a category including fertilizer and seed—by 15 percent on average and increased their crop yield by 13 percent.

Still, many farmers remain skeptical. "I don't think farmers will be excited about these [data-driven recommendations] until they see the payoff," says Carl Dillon, an agricultural economist at the University of Kentucky. *—Nanette Byrnes*

Technology

Watson Makes a Salad

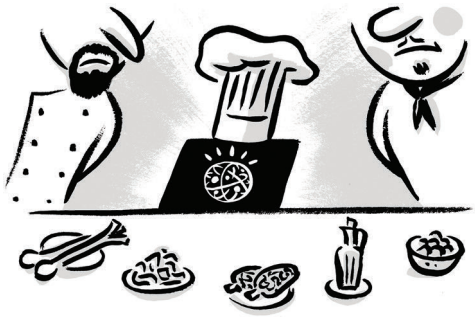
IBM's Watson technology has digested years of research on flavor and taste and memorized 10,000 recipes. Now it's creating recipes that its creators hope are both pleasant and surprising.

● If it sounds like a salad created by a computer, that's because it is. "Morel Mushrooms Leek Katsuobushi Hazelnut Pear Poached" is the recipe that Florian Pinel, lead engineer at the IBM Watson Group, and I came up with (well, mostly Pinel did). To make it we used a beta version of an online extension of the new cookbook *Cognitive Cooking with Chef Watson*. This online engine, powered by IBM's *Jeopardy!*-beating cognitive computing system Watson, allows you to "discover" a recipe by selecting a few key ingredients and then exploring other foods with similar "flavor compounds" in a matchmaking exercise similar to Pandora's method of grouping musical acts by common traits. You can choose to pair the initially chosen foods with those it identifies or substitute one for another.

Pinel, a chef as well as a researcher, had the idea of pairing a spring classic, the morel mushroom, with Japanese bonito fish flakes (katsuobushi), two foods that share a surprising number of common flavors—120 altogether, according to Watson. Using a Western approach—Westerners like recipes consisting of ingredients with shared flavor

Morel Mushrooms Leek Katsuobushi Hazelnut Pear Poached

8 Servings



INGREDIENTS:

(Watson lists these unconventionally, by food type rather than order of inclusion)

SWEETENER: ½ lb. superfine sugar

DRIED FRUIT: 2½ tbsp. raisins

VEGETABLE: 1 sliced leek

¼ cup morel mushrooms

OIL / FAT: ¼ cup grapeseed oil

FRUIT: 4 peeled, halved, cored pears

CONDIMENT: ¼ oz. katsuobushi

LEAF VEGETABLE: 1¼ head Boston lettuce

ALCOHOLIC BEVERAGE: 15 fl. oz. white wine

VINEGAR: 2½ tbsp. white wine vinegar

NUT / SEED / PULSE: ¾ cup toasted hazelnuts

FRUIT JUICE: 1 cup orange juice

CHEESE: 1¼ cup grated Parmesan cheese

SEASONING/SPICE: ¼ oz. ground cloves

SUGGESTED STEPS:

PEARS:

1. Bring the wine, juice, sugar, raisins, and ground cloves to a boil in a wide saucepan over medium-high heat. Stir.

2. Add pears, cut side down.

3. Return the syrup to a boil and reduce the heat to medium-low. Simmer uncovered.

4. Cool completely, cover, and chill.

5. Drain pears and cut each one lengthwise into thin slices, leaving the top one inch at the narrow end intact.

6. Gently press on the pears to fan them slightly.

VINAIGRETTE AND SALAD:

1. Whisk leek, morel mushrooms, white wine vinegar, and katsuobushi in a small bowl to blend.

2. Gradually whisk in the grapeseed oil.

3. Season to taste with salt and pepper.

4. Cover and refrigerate.

5. Toss Boston lettuce in a large bowl to coat with vinaigrette.

6. Put lettuce on plates. Top with a pear half, a sprinkle of hazelnut, and Parmesan cheese.

7. Drizzle with more vinaigrette if desired, and serve.

CHRISTOPH ABBREDERIS

compounds, while Eastern cuisines pair opposites—Watson then suggested other ingredients that it predicted would taste good with morels and fish flakes, including leek, hazelnut, and pear. Watson then searched its memory banks of the 10,000 recipes published by *Bon Appétit* magazine over the past decades to suggest a suitable preparation, a twist on a classic poached pear and blue cheese salad.

To test Watson's culinary imagination, I went shopping, printout in hand. I had trouble finding morels—springtime comes late to Boston—but the fish flakes were easily located in the international aisle at Whole Foods. For the white wine in the dressing I chose a white Bordeaux. In the kitchen, I found Watson's cooking directions to be a bit sparse and sometimes odd (1¼ heads of lettuce, for example), so I did some independent research: I consulted Martha Stewart for how long it takes to poach a pear (20 minutes) and Epicurious for directions on toasting hazelnuts. But overall, the recipe came together nicely, and the panel of taste testers (my family) liked the combination of crunchy nuts and sweet pear. The katsuobushi's flavor was subtle, and I would recommend going light on the Parmesan, but overall I'd give a strong review to a chef who'll never have the pleasure of tasting one of his own creations.

—Nanette Byrnes

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Reviews

The Struggle for Accurate Measurements on Your Wrist

Wearable devices are getting more advanced, but can today's technology really measure our health?

By Rachel Metz

Until recently, I didn't know a thing about how my roughly 25-minute bike commute across San Francisco—or any other part of my day, really—affects my body, other than that I inevitably arrive at work sweaty and a bit out of breath when I'm in a big rush. How high is my heart rate? Do my sleep habits affect it? How many calories do I burn?

These questions have been on my mind as a number of activity trackers and smart watches have hit store shelves over the past couple of years, promising to track information like steps, sleep, heart rate, sun exposure, and calories. With one of these sensor-filled gadgets on my wrist, surely I could get accurate information about my body.

Apple Watch, $349 and up
Microsoft Band, $200
Jawbone Up3, $180

That's the idea, at least. These devices could give you more control over your health by making it easier to collect data previously left unmonitored or, as in the case of heart rate, typically gathered only at a doctor's office (and even then infrequently). And these devices aren't just tracking data; companies like Apple, Jawbone, and Microsoft offer advice based on what the sensors in their wrist-worn wearables detect. The Microsoft Health app should soon have the ability to compare calendar or contact information with the Microsoft Band's assessment of, say, your heart rate or skin conductance level—a measure of your skin's ability to conduct electricity, which tends to climb with stress.

The Apple Watch and Microsoft Band use optical sensors to measure heart rate. The Jawbone Up3, which instead tracks your resting heart rate, uses bioimpedance sensors and several electrodes to measure your skin's resistance to a small amount of electrical current. These sensors and others in the bands are adequate for measuring routine activity levels, but is the technology really accurate enough to turn wearable devices into digital medical tools?

"We're at an inflection point, or transition, from lifestyle health stuff to medical metrics," says cardiologist Eric Topol, a genomics professor at the Scripps Research Institute and a fan of digital health technology. To Topol, the objective is clear: devices that accurately measure vital body signs and even monitor serious health problems like diabetes and heart disease. "It's the medical metrics where accuracy becomes fundamental," he says.

The test

How far away are we from such wearables? I tested the accuracy of a few wrist-measured metrics, including heart rate. For several days, I wore an Apple Watch and a Microsoft Band while biking to and from work. I also wore a Polar H7 Bluetooth chest strap, which is one of the most accurate consumer devices for measuring heart rate. Results varied, and sometimes they varied a lot. The Band's average heart-rate measurements were consistently closer to the results of the Polar chest strap—sometimes within a beat or two per minute, but they could be as many as 13 beats off. The Apple Watch, meanwhile, gave readings as many as 77 beats per minute different from the Polar device.

Measurements of calories burned (something all three bands, including the Up3, track) were also somewhat inconsistent; on one morning commute, for instance, they ranged from 143 to 187.

Altogether, the experience was a far cry from the vision of these devices as

Photographs by Damien Maloney

ital sages drawing deep, accurate insights from the data they collect, helping doctors diagnose ailments, and eventually, perhaps, even predicting health problems or detecting them before they become serious. These are hard goals to achieve, for several reasons. While the wrist seems like a great place to start with sensing on the body, and we're used to adorning it with watches and jewelry, it's tricky to make a comfortable, good-looking device that can stand up to all kinds of daily abuse.

And since everyone's body is different, the wrist is not always a great spot to take accurate measurements. "You can make millions of smart watches that are identical, but you have millions of people who are not identical. It's really hard to find something that's robust across all these people," says Chris Harrison, an assistant professor of human-computer interaction who leads the Future Interfaces Group at Carnegie Mellon University.

Harrison and other experts say arms that are too hairy, sweaty, fat, or thin can make it hard to get a good reading from today's optical heart-rate sensors, which read blood flow in the wrist. Tattoos can pose a problem, too—as Apple points out on a support page for the Apple Watch, noting that the ink can block light from reaching the sensor. "All of a sudden that translates to thousands of users out there, all of whom are going to be unhappy and say it doesn't work because it doesn't work for them," says Christian Holz, a researcher on human-computer interaction at Yahoo Labs who focuses on the miniaturization of mobile devices.

Beyond workout tracking

There's hope for wearable devices that actually take the types of measurements that would be helpful for health monitoring. But realizing that hope will probably mean moving on to radically new technologies. And it will certainly mean developing devices that are able to take a wider variety of measurements.

At Quanttus, a startup in Cambridge, Massachusetts, researchers are building a wrist-worn device to track heart rate, respiration, and blood pressure by way of ballistocardiogram, which uses a sensor to measure the itty-bitty movements of your body every time your heart pumps blood. At a conference in late April, cofounder and CEO Shahid Azim said the company is interested in releasing "some number" of wristbands by the end of the year. Cofounder and chief scientific officer David He says it is still "refining the technology."

Once we can pin down heart-rate and blood-pressure measurements, He believes, we may well be able to monitor most cardiovascular vital signs with wearables. This could be a boon, not just for fitness applications and those wanting to keep an eye on their own health but also for doctors who want noninvasive ways to keep tabs on patients at a level currently possible only in a hospital.

Another Cambridge-based startup, Empatica, is creating a wristband that measures jumps in skin conductance to figure out when the wearer is having a seizure, so it can alert someone to check on the person. Empatica isn't able to predict seizures yet, however, and it hasn't released its product either.

Building these products takes lots of time. Testing, simulations, modeling, prototyping, and problem-solving are all more extensive when you need to make sure the devices can stand up to the requirements of daily wear, such as frequent exposure to sweat and water. That's a lot more than you'd normally expect from your electronics. But if companies clear these obstacles, being able to sense things like blood pressure and skin con-

ductivity continuously can also open the door to quantifying stress and mood, since they will make it possible to collect data about your body in all kinds of situations.

And we're just at the early stages of understanding how much we may be able to do with sensors on the skin. In the next several years, noninvasive sensors may become useful for other biometrics that can currently be tracked only with invasive processes. It might be possible to monitor blood glucose with skin readings rather than a needle prick—something that would be helpful to people with diabetes.

In fact, researchers are working on this particular problem at the University of California, San Diego. They've developed a temporary tattoo, printed with electrodes and coated with an enzyme solution, that can measure glucose levels. Joseph Wang, director of UCSD's Center for Wearable Sensors, has been working on the technology for the past five years. He says it will be at least another two years before it is commercialized—initially, he expects, in the form of a single-use temporary tattoo, and then with tattoos that can measure the wearer's glucose every 20 or 40 minutes for a day or a week. Topol believes that all kinds of accurate data are coming; it's just a matter of time. "We have a ways to go, but ultimately, that is something machines are really very good for," he says. "And the algorithms can be developed where for each person it could be a virtual medical assistant."

Given that today's wristbands still stutter when measuring heart rate during a workout, such applications seem far out of reach. But the research at Quanttus, Empatica, and UCSD suggests that new approaches based on technologies far beyond conventional optical sensors could finally turn wrist-worn devices into tools for monitoring general health.

Rachel Metz is MIT Technology Review*'s senior editor for mobile.*

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The Wait-for-Google-to-Do-It Strategy

America's communications infrastructure is finally getting some crucial upgrades because one company is forcing competition when regulators won't.

By James Surowiecki

BRECHT VANDENBROUCKE

It's too often said that some event "changed everything" in technology. But when it comes to the history of broadband in the United States, Google Fiber really did. Before February 2010, when Google asked cities to apply to be first in line for the fiber-optic lines it would install to deliver Internet service to homes at a gigabit per second, the prospects for upgrading Americans' wired broadband connections looked dismal. The Federal Communications Commission was on the verge of releasing its first National Broadband Plan, which stressed the importance of affordable, abundant bandwidth and the need to spread it by "overbuilding"—stringing fiber to houses and businesses even if they already had service over cable and phone lines with relatively low capacity. Yet at the time, as Blair Levin, executive director of the broadband plan, told me, "for the first time since 1994, there was no national provider with plans to overbuild the current network."

This was not because of technological hurdles. Instead, it was a simple matter of incentives. Building much faster networks was an expensive task, one that would require the kind of hefty capital expenditures that Wall Street typically frowns upon. (Verizon's spending on its FIOS TV and high-speed Internet service, for instance, came in the face of deep skepticism from investors, which eventually led the company to curtail its expansion of FIOS nationally.) And since Internet service in most cities was supplied by either a near monopoly or a cozy duopoly in which the two players—typically a cable company and a major telecom provider—barely competed against each other, there was little competitive pressure to improve. As long as all the players kept the status quo intact, it seemed, Internet providers could look forward to years of making sizable profits without having to put much money into their networks. The Internet as we know it was only 15 years old,

but ISPs were already shifting into harvesting mode: maximizing revenue from their infrastructure rather than upgrading it. Forget gigabit Internet. The National Broadband Plan set a goal of getting 100 million homes affordable access to download speeds of just one-tenth of a gigabit, or 100 megabits, per second. (Only 15 percent of American homes have connections above 25 megabits now.)

Google Fiber
Gigabit Internet plans start at $70 a month

National Broadband Plan
March 17, 2010
www.fcc.gov/national-broadband-plan

State and local governments had done little to disrupt the status quo or push ISPs to invest in upgrades. And governments also showed little interest in subsidizing, let alone fully paying for, a better infrastructure themselves. (There was money allocated to broadband investment in the 2009 stimulus bill, but it went mainly to wire underserved areas rather than lay fiber.) On the municipal level, most cities still had building regulations and permit requirements that, inadvertently or not, tended to discourage the laying of new line, particularly by new entrants. And in many cases, even if cities were interested in building or operating their own high-speed networks, state laws barred them from doing so. The result of all these factors was that the United States, slowly but certainly, began falling well behind countries like Sweden, South Korea, and Japan when it came to affordable, abundant bandwidth.

Five years later, things look very different. The United States is still behind Sweden and South Korea. But fiber-to-the-home service is now a reality in cities across the country. Google Fiber, which first rolled out in Kansas City in the fall of 2012, is now operating in Austin, Texas, and Provo, Utah, and Google says it will expand next to Atlanta, Salt Lake City, Nashville, and Charlotte and Raleigh-Durham, North Carolina, with another five major metro areas potentially on the horizon. The biggest impact, though, has arguably been the response from big broadband providers. In the wake of Google Fiber's debut, AT&T announced that it would begin offering one-gigabit connections at prices that would previously have seemed impossible, and the company says it might expand that service into a hundred cities. CenturyLink and Cox now have gigabit service in a few cities, and Suddenlink promises an offering in the near future. (Whether such promises will be kept is, of course, a different question, but the mere fact that they've been made is striking.) And even in areas where gigabit connections may be a long time coming, cable companies have dramatically improved speeds for their customers, often at no added cost. Time Warner Cable—one of whose executives declared, at a public conference, that it wasn't offering gigabit service because consumers didn't want it—offers connections today that are five times the speed of what was its fastest connection a couple of years ago.

The share of the country's homes connected to fiber lines is still only about 3 percent. But compared with where the U.S. was just a few years ago, progress has been dramatic.

Google Fiber has also inspired action on the municipal level. Gig.U, of which Blair Levin is now executive director, is working on bringing gigabit connections to more than two dozen college towns (where the demand for ultra-high-speed connections is obvious). A consortium of cities in Connecticut is talking with the Australian investment bank Macquarie about a public-private partnership to build a fiber network that the cities would eventually own (an approach similar to the one Stockholm used to build its fiber network). Seeing how Chattanooga, Tennessee, went ahead and built its own network, wiring every home with fiber, cities everywhere are looking to streamline their permit processes in order to make laying these new networks as simple (and affordable) as possible. "When you talked to mayors a few years ago, they would tell you about all the other problems they had that mattered much more than bandwidth," Levin says. "When you talk to them today, they recognize that this is something they really need, and that it isn't about streaming TV but about making sure businesses and schools and health-care facilities are going to have what they need in the future."

None of this means that we've reached a true tipping point when it comes to fiber. The share of the country's homes connected to fiber lines was still only about 3 percent at the end of 2013. But compared with where the U.S. was just a few years ago, progress has been dramatic. Had Google not chosen to do what it did, we'd probably still be stuck with the lack of investment and slow downloads that were our lot in 2010. As Levin puts it, "I would like to believe that all this happened because we made such a brilliant case for the benefits of abundant bandwidth in the National Broadband Plan. But that's not the case. Without Google, this would not have happened."

That raises the obvious question, of course, of just why Google did this, given that investing in physical networks is a long way from its core business. Google Fiber was introduced as "an experiment," but as it has expanded, the company has said that it views the project as a real business and is managing it that way. And obviously, even if the direct return on the

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investment in Google Fiber ends up being small (as seems likely, given that Google is charging similar prices for gigabit connections as cable companies charge for much slower ones), the company will reap ancillary benefits from making the Internet more valuable and driving more traffic online.

In the end, though, the reason Google has invested in fiber is less important than the practical outcome of that investment. In effect, what the company is doing—both in building these networks and in pushing national providers to upgrade—is providing a public good whose spillover benefits are likely to be immense, and one that neither the government nor the private sector was doing much to deliver. This is somewhat similar to what Google did, on a smaller scale, back in 2008, when the FCC was auctioning off sections of the airwaves to wireless providers. The FCC had announced that if bids for a certain slice of the spectrum exceeded $4.6 billion, it would attach an open-access requirement that existing wireless providers didn't want to have to follow. So Google placed a bid that was above the FCC's price. It did so not in the expectation of winning (though it was prepared to spend the money if it did) but, rather, in order to ensure that regardless of who won—in this case, Verizon—the open-access requirement would go into effect. One might speculate that a similar dynamic is at work in Project Fi, Google's new wireless-service offering, which challenges most wireless providers' traditional pricing strategies (as well their dependence on privately owned networks).

What Google's doing, in these cases, is using its deep pockets in the interest of broader social ends, with seemingly little concern for short-term returns. This strategy has historical precedent. In the early years of the American republic, there was little appetite for government spending on public works, like roads and canals. But the country needed better roads to facilitate the growth of trade and commerce. So the states turned to private companies, which built turnpikes that they then operated as toll roads. In the late 18th and early 19th centuries, hundreds of these companies invested millions of dollars in laying thousands of miles of road, in effect providing the basic infrastructure for travel in the United States.

What's interesting about these companies is that while they were, in theory, for-profit, and while they had shareholders, in most cases there was no expectation that they would actually turn a profit in operating the roads—tolls were kept low enough to encourage traffic and commerce. Instead, the shareholders—who were typically local merchants and manufacturers—saw their investments in turnpikes as a way to collectively provide a public good that, not incidentally, would also deliver benefits to them as business owners and consumers. They knew, of course, that other businesses would benefit from these roads even if they didn't invest in them (the nature of a public good being that everyone can use it). But that didn't mean the investment wasn't worth making. It's hard not to see a similar logic underlying much of what Google does.

The unnerving thing is that so much of the present and future of broadband has come down to the whims of a single company.

When it comes to the current state of innovation and the economy, the implications of Google Fiber are complicated. On the one hand, it is a testament to the power of competition. Google's willingness to invest the money in a new network threatened cable and telecommunications companies' dominance, and took customers away from them. That shifted the economic calculus. It's no coincidence that the cities and regions where cable companies first announced they were building fiber, and offering high-speed connections at affordable prices, have been the places where Google Fiber either is or is going.

At the same time, though, it's depressing that ensuring competitive broadband markets required the intervention of an outsider like Google. Indeed, the system as it was five years ago was designed to keep us stuck in the broadband dark ages. The government didn't really do anything to change that, either by acting to make markets more competitive or by investing on its own. We just got bailed out by Google.

The unnerving thing is that so much of the present and future of broadband has come down to the whims of a single company, and a company that, in many ways, doesn't look or act much like most American firms. If Google didn't have such a dominant position in search and online advertising, giving it the resources to make big investments without any requirement of immediate return, Google Fiber wouldn't have happened. And if Google's leadership weren't willing to make big long-term investments in projects outside the core business, or if the company didn't have a dual-share structure that preserved its founders' power and somewhat insulated its executives from Wall Street pressure, gigabit connections would more than likely be a fantasy in the United States today. As Levin puts it, "We got fortunate that a company with a real long-term view came into this market." It might be good to design technology policy so that next time around, we don't need to get so lucky.

James Surowiecki writes "The Financial Page" for the New Yorker. *His last article for* MIT Technology Review *was about Uber's dynamic pricing algorithm, in September/October 2014.*

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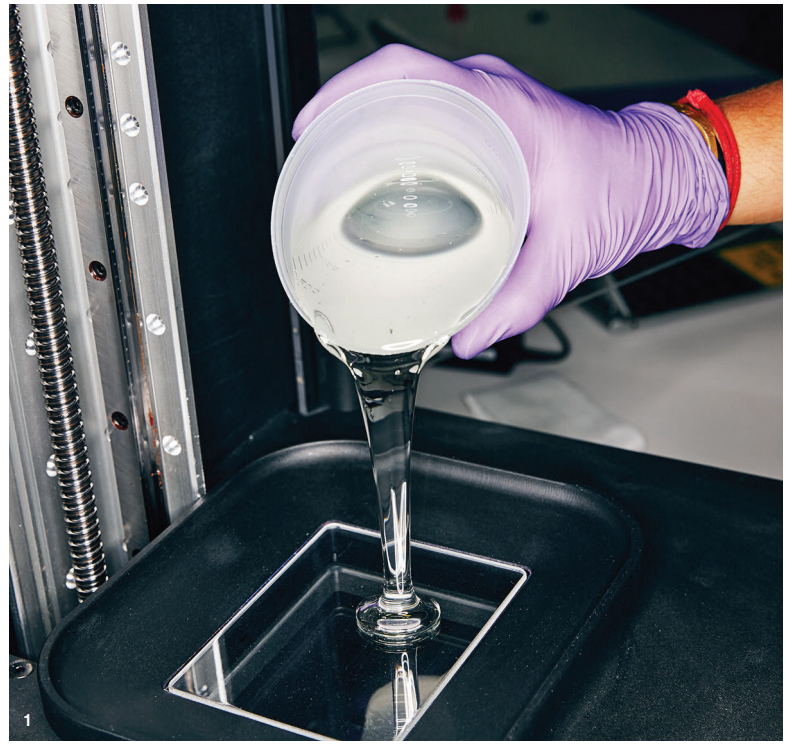
Demo

Speeding Up 3-D Printing

A company's novel technology could make custom medical devices and car parts—not to mention shoes that fit just right.

By Katherine Bourzac
Photographs by RC Rivera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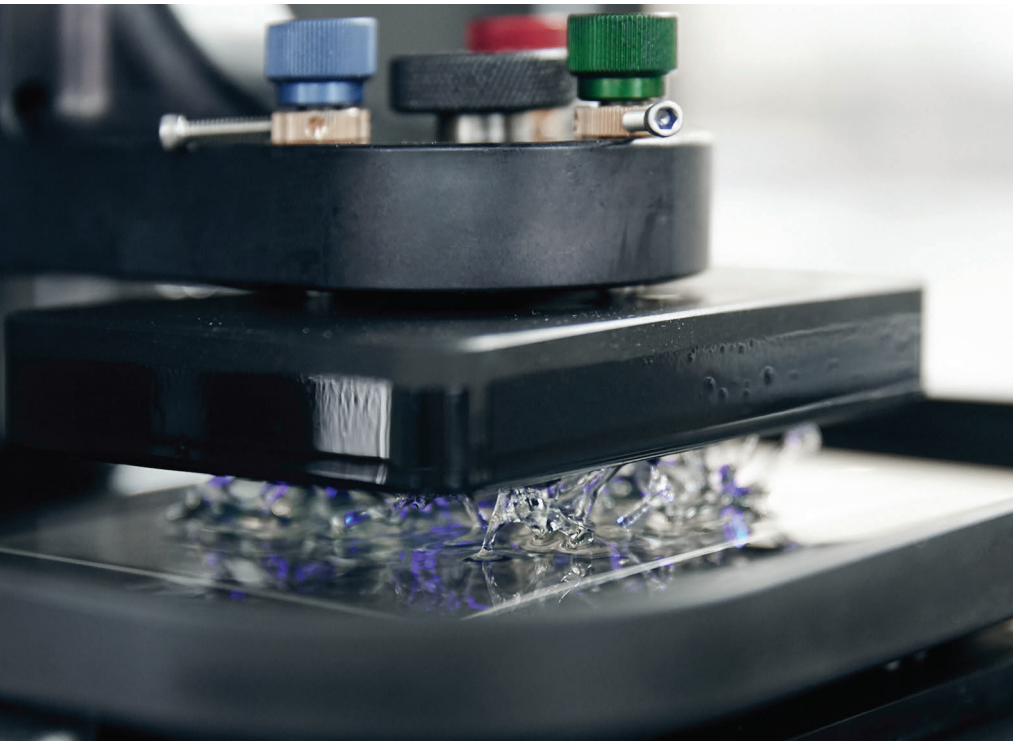
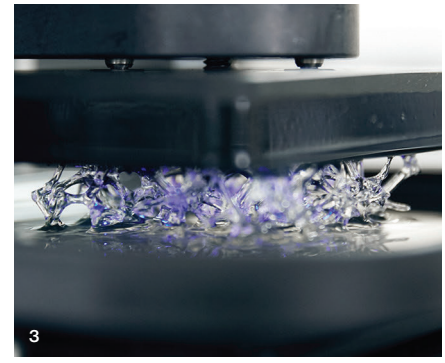
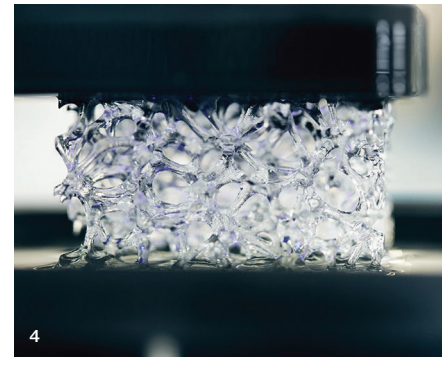
3-D printers can make objects that are impossible or expensive to make with molding, milling, and other conventional manufacturing processes. However, these printers work too slowly to be widely used in factories.

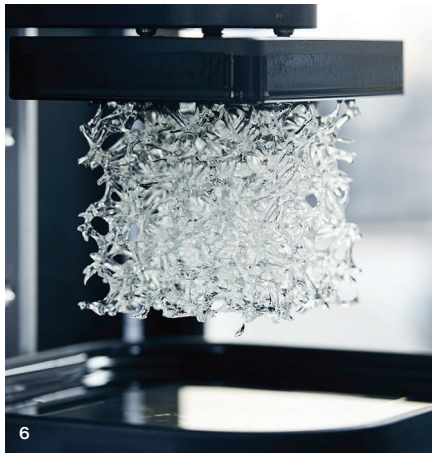
That's because today's version of the technology builds up objects one layer at a time. It's essentially 2-D printing over and over again, says chemical engineer Joseph DeSimone, founder and CEO of Carbon 3D, a startup in Redwood City, California. His company claims to have a technology that is 25 to 100 times faster, depending on the object and the material.

DeSimone hopes Carbon 3D's printers will be used to make airplane or car parts that are stronger and yet lighter









1 A technician pours viscous polymer precursors into the printer well. The window at the bottom lets in light from an underlying ultraviolet-light projector and is permeable to oxygen.

2–6 Frame by frame, the ultraviolet light projects the design into the chemical bath. Some of the light is visible as a violet glow. As the exposed chemical precursors harden, a mechanical arm pulls the growing object out of the bath. A thin layer of oxygen at the bottom of the bath keeps the hardening patterns from sticking.

7 A technician removes the completed object, which took 17 minutes to print. The company says this structure can be made in seven minutes when the process is not slowed down for photographs.

8 This is an enlarged model of the structure of bone. A pattern like this can't be made using a mold, and it would be very involved to make by milling away material from a solid polymer block.

9 A pattern of struts inside this 3-D-printed cylinder of hard resin adds extra strength without adding much weight. This kind of design might be used to replace metal support structures in airplane seats, according to the company.

10–11 The printers can also build objects from bouncy, flexible elastomers, which could be well suited for wearable items like shoe soles and headphones. Elastomers are incompatible with traditional additive manufacturing, says DeSimone.

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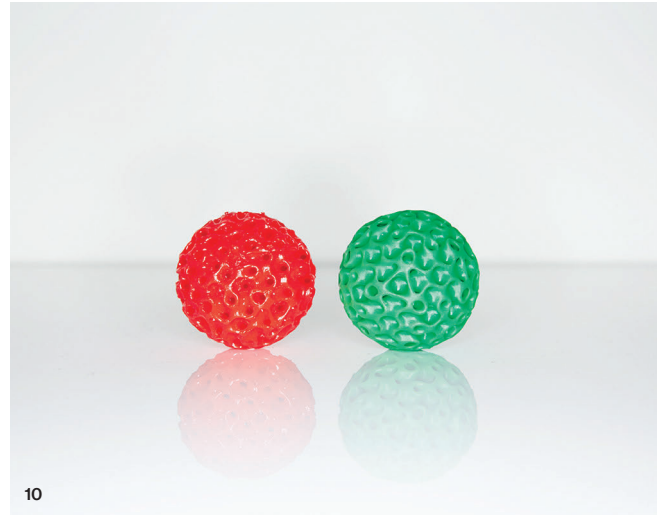

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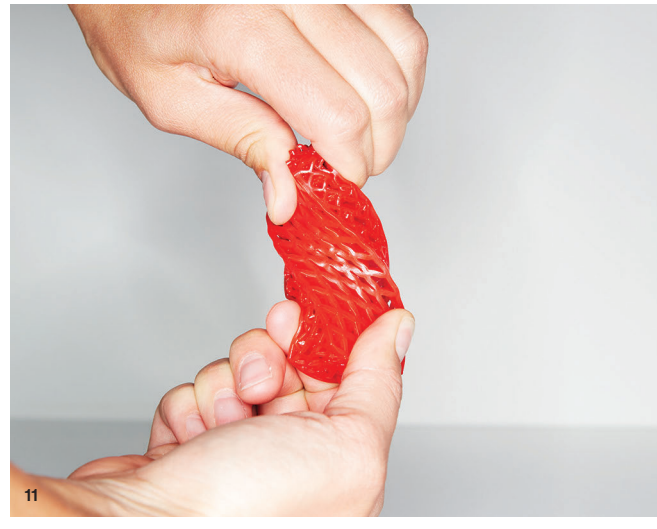

11

than ones used today, helping to reduce fuel consumption. He also wants to make it possible to rapidly print custom shoe soles, fitted to the quirks of individual arches, and place printers in operating rooms to generate stents matched to patients' arteries.

Carbon 3D's process is a variation on a method called stereolithography, which uses projected patterns of ultraviolet light to catalyze the formation of solid polymers from a pool of resin. Stereolithography is typically a stop-and-start process—the object being printed sticks to the bottom of whatever vessel it's in and must be pried off after each flash of light. Repeating this process with each layer is slow and leaves the completed object mechanically weak where each layer connects to another.

In Carbon 3D's version, the pool of liquid resin sits in a vessel with a window at the bottom. The window is permeable like a contact lens, so it lets in not only light but also oxygen—which inhibits the chemical reaction just enough to prevent the polymer from solidifying on the bottom. That allows Carbon 3D to continuously print one layer on top of the next, which makes the process much faster and the resulting materials stronger, says DeSimone. "It looks like something growing out of a puddle," he says.

Other researchers have demonstrated printing systems that incorporate some of the techniques used in Carbon 3D's machines, and some of these methods can print features with higher resolutions than the company's process. DeSimone, who founded Carbon 3D in 2013 and is on leave from the University of North Carolina to work at the company, has $51 million in funding to further develop the printers and polymer materials that will be its first products. This March, the company came out of stealth mode with a *Science* paper describing its technology and a captivating video of a small blue model of the Eiffel Tower emerging rapidly from a viscous little pool.

DeSimone says that while most commercial 3-D printing systems have been designed by mechanical engineers, his chemistry focus sets Carbon 3D apart. "We want to offer materials properties that haven't been seen before," he says.

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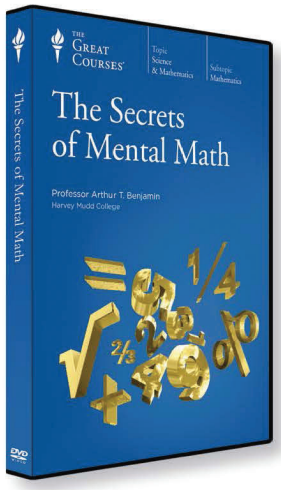

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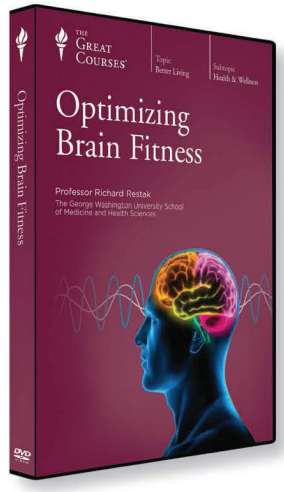

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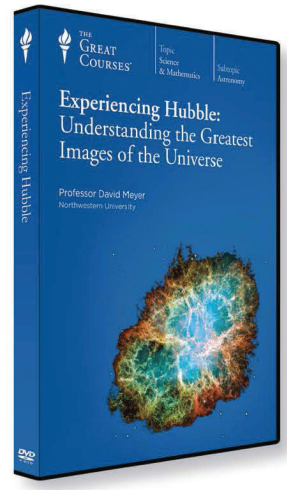

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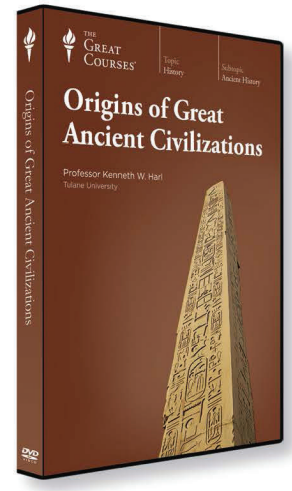

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Excerpted from "Machinery and Unemployment," by Dugald C. Jackson, head of MIT's Department of Electrical Engineering from 1907 to 1935, in the March 1933 issue of Technology Review.

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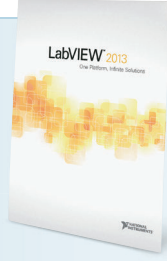

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